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Some Notable Electrical Engineering Features in and near New York

Open to A. I. E. E. Members and Guests at Midwinter Convention

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Cipher Printing Telegraph Systems

For Secret Wire and Radio Telegraphic Communications

BY G. S. VERNAM[1]

Associate, A. I. E. E.

***Synopsis.**—This paper describes a printing telegraph cipher system developed during the World War for the use of the Signal Corps, U. S. Army. This system is so designed that the messages are in secret form from the time they leave the sender until they are deciphered automatically at the office of the addressee. If copied while en route, the messages cannot be deciphered by an enemy, even though he has full knowledge of the methods and apparatus used. The operation of the equipment is described, as well as the method of using it for sending messages by wire, mail or radio.*

The paper also discusses the practical impossibility of preventing the copying of messages, as by wire tapping, and the relative advantages of various codes and ciphers as regards speed, accuracy and the secrecy of their messages.

* * * * *

INTRODUCTION

THE purpose of this paper is to discuss briefly certain methods for obtaining secrecy in connection with messages sent by wire or radio telegraphy, and to describe in particular printing telegraph cipher systems that were developed for this purpose during the World War.

The desirability of obtaining secrecy in telegraphic communications and the possible advantages of a system that would be capable of sending messages in such form as to be entirely secret, and which at the same time, would be more rapid and accurate than the codes and ciphers ordinarily used, were brought out in conversations with officers of the Signal Corps, U. S. Army. These discussions made it evident to the engineers of the Bell System that it would be very helpful if the well-known automatic features of the printing telegraph art could be made available for enciphering and deciphering telegraph messages, and could at the same time be made practical for use under service conditions.

The engineers recognized that printing telegraphs[2] were rapid and accurate, but were not secret except to the extent that their signals could not be read from a telegraph sounder. With the general requirements for secrecy systems in mind, studies were made of printing telegraph systems to determine how their messages could be made secret. The result of this work was the development of a cipher system that is capable of rendering messages entirely secret, is rapid and accurate, and is practical to use.

This "Cipher Printing Telegraph System" was called to the attention of the Signal Corps. The Signal Corps became very much interested, tested the secrecy of communications handled by the system and tried it out between New York and Washington. This trial proved that the system could be successfully used to send messages secretly and at a speed many times faster than by methods previously in use.[3]

Each message is automatically enciphered at the sending station and deciphered in the same manner at the receiving station. The method of ciphering will be described later in this paper and is such that under certain conditions of use, the messages are rendered entirely secret, and are impossible to analyze without the key, even if it is assumed that the enemy can capture a machine, learn its method of operation in all details, and intercept a large number of messages.

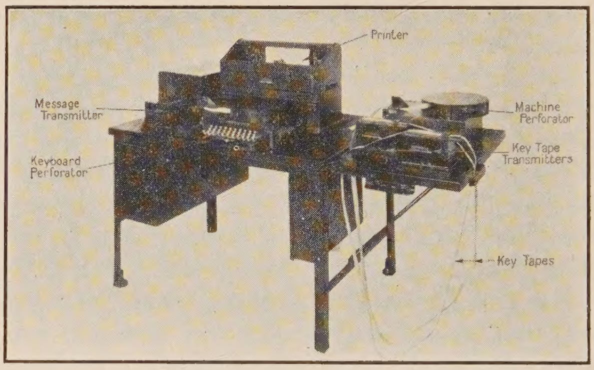

FIG. 1—CIPHER PRINTING TELEGRAPH MACHINE

FLEXIBILITY OF SYSTEM

This method of ciphering can be used with machines of various types. The electrically-driven machine shown in Fig. 1 was developed during the war particularly for the Signal Corps, U. S. Army. In order to save time in production, standard printing telegraph parts were used wherever possible with the result that this machine has the appearance of a "start-stop" printing telegraph set with some additional units mounted on a shelf at the right end of the table. This type of cipher set is particularly suitable for handling large amounts of traffic at high speed.

1. Engineer, Dept. Development and Research, Am. Tel. & Tel. Co.

2. See John H. Bell, "Printing Telegraph Systems," TRANS. A. I. E. E. for 1920, Vol. XXXIX, Part 1, p. 167, and A. H. Reiber, ' Printing Telegraph Systems Applied to Message Traffic Handling," TRANS. A. I. E. E. for 1922, Vol. XLI. p. 39.

To be presented at the Midwinter Convention of the A. I. E. E., New York, Feb. 8-11, 1926.

3. Note: See page 140, "Report of the Chief Signal Officer to the Secretary of War" for the year ending June 30, 1919.

If something smaller in size and portable is required, the machine shown in Fig. 2 may be used. This machine is light and strictly portable as no electric current is required for its operation. It is slower than the large machine and requires a knowledge of the standard "Baudot" printer code (see Fig. 8) on the part of the operator, but its messages are equally secret.

These machines are considered suitable for general use by government departments, business concerns,

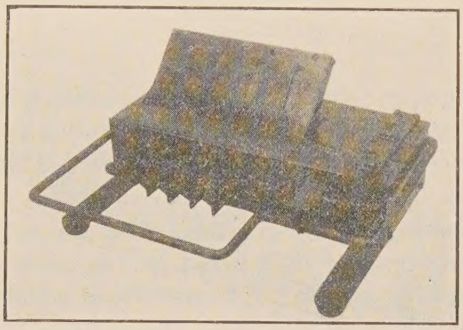

Fig. 2—Portable Cipher Machine

etc., for handling confidential messages rapidly and secretly. The method of using them can be varied to suit conditions and so as to make unauthorized decipherment as difficult as may be necessary up to the point where it becomes impossible even for an expert cryptanalyst.

If an appreciable demand exists for machines of special sizes or having particular operating features for special uses, these can be built to employ the same secrecy principle. For example, the functions of ciphering and transmitting over a telegraph circuit can be combined in one machine, if desired, so that, at the sending station, messages can be simultaneously enciphered and transmitted over the telegraph circuit, and so that, at the receiving station, messages can be received, deciphered automatically and printed directly in plain text; thus avoiding the slight delay caused by separately enciphering and deciphering each message. This method is particularly suitable for cases where the cipher equipment can be directly connected to a telegraph line or to a radio transmitter and receiver and can be operated by the same personnel.

RUIYW TGCZG PIETY RJGUA ELKEJ EZIAO
ISCFE LCXHF CONEC XELVY DXJBT WFEJM
HLGDL DDPYD TPGVQ EZAYI LXSZX

Fig. 3—Sample Cipher Message in Printed Form

If the cipher messages are to be turned over to a telegraph or cable company to transmit, they should be in written or printed form. For this purpose, the cipher machine can be arranged to print the cipher messages in groups of five letters each, spaced to form "words." Fig. 3 is a copy of such a message shown exactly as it was prepared by the cipher set. Such messages can be printed by the machine directly on the telegram blank with the address and signature in plain English, and if desired, a carbon copy can be made at the same time for record purposes.

Preventing Access to Messages

There appear to be two general methods for securing secrecy in connection with communications, namely, (1) by preventing or at least attempting to prevent access to the messages or to the lines of communication and, in the case of telegraphic communications by rendering the lines incapable of being tapped, and (2) by the use of codes and ciphers with key systems known only to the proper parties.

As regards wire tapping, sensitive alarm devices arranged to operate on small changes in the electrical constants of the line circuit, are unsuccessful as a means of preventing unauthorized parties from obtaining access to the circuit. The electrical condition of a long telegraph circuit is continually changing as a result of variation in temperature and other weather conditions. This fact limits the useful sensitivity of any such alarm devices, whereas by using vacuum tube amplifiers, a record of the signals passing over a circuit can be obtained without appreciably disturbing the line circuit and even without actual contact with the wire.

Telegraph systems have been invented, that will operate successfully on very small line currents, and which use coils and condensers to suppress the harmonics in the signal impulses, or in other words to avoid sudden changes in current value. The currents induced in neighboring circuits by such a system would be small, so that it would be rather difficult, if ordinary methods are used, to obtain a record of the signals by their inductive effect. This can be readily done, however, if modern vacuum tube amplifying equipment is used. It is also obvious that a record can be easily obtained if the wire is tapped.

Many attempts have been made to obtain secrecy during the actual transmission of telegraph messages by making them unintelligible. In one system of this sort, successive signal impulses are sent alternately over two line wires by means of a rotary switch which puts the sending key in connection first with one wire and then with the other at each movement of the key. At the receiving end, the impulses are combined through one relay. With this system, the messages may be readily copied if both wires are tapped, and it is quite possible to decipher the messages even if only one wire is tapped.

Proposals have also been made to use complex devices or methods, or so to mutilate the normal impulses that they become unintelligible to anyone tapping the line circuit or intercepting the signals if sent

by radio. Any secrecy system of this general class can be readily "broken" by anyone having a knowledge of the methods used and the ability to assemble and operate the necessary apparatus.

Tapping Duplex and Multiplex Circuits

It has also been considered that a full duplex circuit or a multiplex printer circuit, in which messages are being transmitted simultaneously in opposite directions, could not be tapped and that circuits of this character insured secrecy to the communications thus being handled. This is not true, however, and means have been invented by which a message originating at one station of an ordinary duplex circuit can be tapped at any part of the circuit, even though a second message is also going over the same circuit simultaneously in the opposite direction. This means that a multiplex printer circuit, in which as many as eight messages, four in each direction, are handled simultaneously, may be tapped and a person who is familiar with the system can readily analyze the multiplex impulses to distinguish between adjacent channels and the letters of each message in each channel.

An arrangement for tapping a duplex circuit is shown in Fig. 4. A single sensitive polar relay may be used to receive the signals from either end of the circuit, or by using two such relays, the signals in both directions may be read simultaneously. Each relay may control a sounder or a suitable recording device. One winding of each relay is connected in series with the line, the other winding being connected in a circuit from line to ground through an "artificial line" composed of adjustable resistances and con-

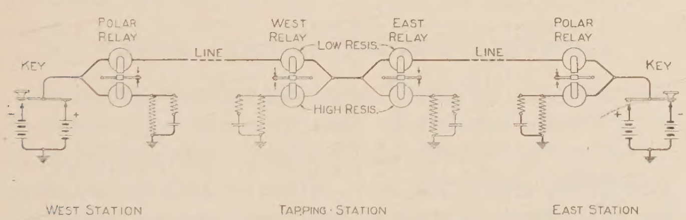

Fig. 4—Method of Tapping a Duplexed Line

densers. The line winding of each relay should have relatively few turns and should be of low resistance, the other winding having a large number of turns. Each artificial line should be adjusted to be substantially equivalent to the impedance of the corresponding section of line including that of the terminal station equipment multiplied by the ratio of turns of the relay windings.

Signals transmitted from the west station will pass through the line windings of both relays at the tapping station, a small part of the signal currents also going through the lower windings and artificial lines to ground. The signal currents pass through both windings of the west relay in series, the magnetic effects of the two windings aiding each other, so that the armature of this relay will follow the signals. The same signals pass through both windings of the east relay in parallel, the magnetic effects opposing and balancing so that this relay does not respond to signals from the west station.

In a similar manner, signals from the east terminal station will energize the east relay but not the west relay at the intermediate station, so that by using suitable recording devices associated with each relay, a copy of signals in both directions may be obtained.

Tapping a Multiplex Circuit

This method may be used to tap a multiplex printer circuit, in which case a tape record of the form shown in Fig. 5 will be obtained. If this is taken from a

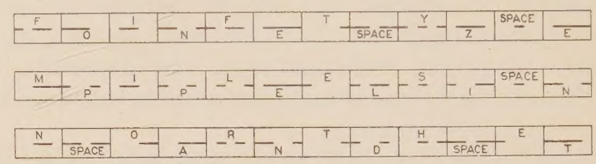

Fig. 5—Tape Record of Multiplex Printer Signals

"double-duplex" circuit alternate letters must be read as indicated, to get the message from either channel. Every third or every fourth letter must be chosen if the circuit is operated by the "triple-duplex" or "quadruple-duplex" method. The individual letters are in the ordinary five-unit printer code, the polarities of alternate signals being reversed. To decipher such a tape, it should be divided into units of five dot lengths each. The correct starting point can be found in not more than five trials and can be recognized by the fact that the letters of each message then form sensible combinations.

Codes and Ciphers

Secrecy, in connection with telegraphic communications, is usually obtained at the present time by means of codes and ciphers, the term "code" being applied in cryptography to the method in which entire words, or phrases of a message are replaced by arbitrary groups of letters or numbers usually printed in a code book, identical copies being kept by those using the code, "cipher" referring usually to a system in which the individual letters of a message undergo a change either in arrangement or nature.

It is obvious that the combinations of letters in a cipher message will not form pronounceable groups or genuine words except occasionally by accident, but "code" systems can be arranged to use pronounceable artificial "words" or actual dictionary words, if desired. This is usually done, as such "code words" are handled by the telegraph and cable companies at a cheaper rate than the unpronounceable so called cipher "words."

Each of these two general systems has advantages and disadvantages which cause them to be used for

certain classes of work, depending upon the conditions. The code system has the outstanding advantage, especially for commercial work, of enabling messages to be shortened so that the tolls are reduced, and it is chiefly for this reason that commercial codes are used. Code is not very accurate, as a mistake in a single code group or even a single letter may change the meaning of an entire message, or necessitate its repetition. If secrecy is required, it is necessary to use carefully guarded private code books, the maintenance of secrecy and accuracy during the printing and distribution of which may cause great trouble. Such books must be carefully used to maintain secrecy, and must be immediately replaced, sometimes at great expense and inconvenience if they should become compromised.

Ciphers, in general, are slower than codes unless machines are used, but then they may be very much faster. They are more accurate, and depending on the system used, cipher messages may be more or less secret than code messages.

There are two general classes of ciphers, known respectively as transposition ciphers and substitution ciphers. In the first class, as the name suggests, the letters of the original message are rearranged, according to a definite system, and in the second class, substitutions for the original letters are made according to some prearranged key. In one, the relative positions of the letters are changed and in the other, the letters themselves.

Transposition Ciphers

A transposition cipher may be distinguished from a substitution cipher by a study of the frequency of occurrence of the letters of the message by comparison with a frequency table of the language of the original message. Studies which we have made of the frequency of the different letters of the English language as they occur in telegrams sent over our private wires, indicate that they are used about as shown in Fig. 6. It is apparent that some letters are used very frequently, the vowels a, e, i, o, u, forming approximately 40 per cent. of the total, e being the most commonly used letter of all. [4]This chart is similar to those used by cipher experts.

In a transposition cipher the letters must be rearranged according to a definite system known to the receiving correspondent. Those who make a study of ciphers tell us that such systems are usually easy to discover, particularly if a considerable number of messages are intercepted including two or more of exactly the same length. Transposition ciphers are not suitable for use with machines.

Substitution Ciphers

In substitution ciphers the order of the letters remains unchanged, but for each letter is substituted its equivalent in one or more cipher alphabets. For example, using the table below, for each letter in the plain text alphabet we may substitute its equivalent in the cipher alphabet. To decipher, this process is reversed.

Plain Text–A B C D E F G H I J K L M N O P Q R S T U V W X Y Z
Cipher –F Q R U K A H G Z S E M L Y P O B C J V D T X W N I

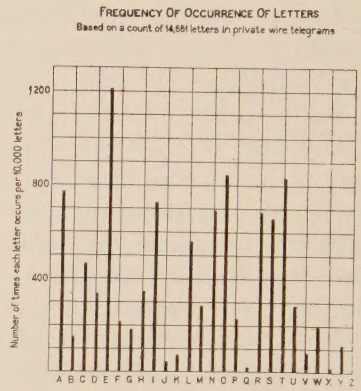

Fig. 6

If a chart is prepared from a frequency count of the letters in such a cipher message, it will have the general appearance of Fig. 6 but the crests will correspond to different letters. Messages of this type are readily deciphered by an expert even when a "mixed" alphabet

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
A	E	G	F	R	A	C	B	Q	M	J	K	Z	I	O	N	Y	H	D	U	W	S	X	T	V	P	L
B	G	N	Q	T	O	H	A	F	X	L	P	J	S	B	E	K	C	W	M	D	V	U	R	I	Y	Z
C	F	Q	R	U	K	A	H	G	Z	S	E	M	L	Y	P	O	B	C	J	V	D	T	X	W	N	I
D	R	T	U	J	E	K	W	X	P	D	F	N	Y	L	Z	I	V	A	S	B	C	Q	G	H	M	O
E	A	O	K	E	D	S	N	Y	V	R	C	W	X	G	B	Q	P	J	F	Z	U	I	L	M	H	T
F	C	H	A	K	S	J	Q	B	L	F	D	I	Z	P	Y	N	G	U	E	X	R	W	V	T	O	M
G	B	A	H	W	N	Q	L	C	S	Z	Y	G	M	E	O	V	F	T	I	R	X	P	D	U	K	J
H	Q	F	G	X	Y	B	C	O	J	I	N	P	T	K	H	L	A	V	Z	M	W	R	U	D	E	S
I	M	X	Z	P	V	L	S	J	W	H	T	F	A	Q	U	D	N	Y	G	K	O	E	I	B	R	C
J	J	L	S	D	R	F	Z	I	H	A	U	B	Q	T	W	X	M	E	C	N	K	Y	O	P	V	G
K	K	P	E	F	C	D	Y	N	T	U	A	X	W	H	Q	B	O	S	R	I	J	Z	M	L	G	V
L	Z	J	M	N	W	I	G	P	F	B	X	T	C	D	R	H	S	O	Q	L	Y	V	E	K	U	A
M	I	S	L	Y	X	Z	M	T	A	Q	W	C	G	U	V	R	J	P	B	H	N	O	K	E	D	F
N	O	B	Y	L	G	P	E	K	Q	T	H	D	U	W	A	F	I	Z	V	J	M	S	N	X	C	R
O	N	E	P	Z	B	Y	O	H	U	W	Q	R	V	A	G	C	K	L	X	T	I	M	J	S	F	D
P	Y	K	O	I	Q	N	V	L	D	X	B	H	R	F	C	T	E	M	W	P	Z	G	S	J	A	U
Q	H	C	B	V	P	G	F	A	N	M	O	S	J	I	K	E	Z	X	L	U	T	D	Y	R	W	Q
R	D	W	C	A	J	U	T	V	Y	E	S	O	P	Z	L	M	X	R	K	G	F	H	B	Q	I	N
S	U	M	J	S	F	E	I	Z	G	C	R	Q	B	V	X	W	L	K	D	Y	A	N	P	O	T	H
T	W	D	V	B	Z	X	R	M	K	N	I	L	H	J	T	P	U	G	Y	O	Q	C	A	F	S	E
U	S	V	D	C	U	R	X	W	O	K	J	Y	N	M	I	Z	T	F	A	Q	E	B	H	G	L	P
V	X	U	T	Q	I	W	P	R	E	Y	Z	V	O	S	M	G	D	H	N	C	B	L	F	A	J	K
W	T	R	X	G	L	V	D	U	T	O	M	E	K	N	J	S	Y	B	P	A	H	F	Z	C	Q	W
X	V	I	W	H	M	T	U	D	B	P	L	K	E	X	S	J	R	Q	O	F	G	A	C	N	Z	Y
Y	P	Y	N	M	H	O	K	E	R	V	G	U	D	C	F	A	W	I	T	S	L	J	Q	Z	B	X
Z	L	Z	I	O	T	M	J	S	C	G	V	A	F	R	D	U	Q	N	H	E	P	K	W	Y	X	B

Fig. 7

is used, such as that illustrated above in which the letters of the cipher alphabet are not in the usual alphabetic order.

By using more than one alphabet, the cipher may be made more difficult to "break." The method may

4. See "Manual for the Solution of Military Ciphers" by Lt. Col. Parker Hitt.

be described by referring to the "cipher square" shown in Fig. 7. In this table, the top alphabet represents the plain text, whi e below it are shown 26 cipher alphabets, each designated by a "key" letter given in the left-hand column. Some form of key, usually a word, is used, the letters of this key word designating the alphabets and the order in which they are to be used. A different cipher alphabet is used in a repeating manner, with each successive letter of the message.

This type of cipher may be distinguished by the fact that the frequency chart is rather flat, the frequency of occurrence of all letters being roughly the same. Each cipher alphabet is used repeatedly at regular intervals. By first finding this interval and then studying each alphabet separately, messages of this type can be deciphered readily by an expert.

Running Key Ciphers

If the key used with this type of cipher is made very long, so that it never repeats and if any portion of this key is never used for more than one message, the operation of "breaking" the cipher becomes very much more difficult. If, now, instead of using English words or sentences, we employ a key composed of letters selected absolutely at random, a cipher system is produced which is absolutely unbreakable.

This method, if carried out manually, s slow and laborious and liable to errors. If errors occur, such as the omission of one or more letters, the messages are difficult for the recipient to decipher. Certain difficulties would also be involved in preparing, copying and guarding the long random keys. The difficulties with this system are such as to make it unsuitable for general use, unless mechanical methods are used.

Cipher Printing Telegraph System

By using machine methods, this type of cipher may be made practicable for use. Fig. 1 is an illustration of the cipher machine previously referred to, and which operates on this principle. As previously mentioned, this machine was developed during the recent war and adopted by the Signal Corps, U. S. Army.

Certain parts of this machine are the same as those used for ordinary printing telegraphs, such as those described in recent papers before the Institute. For this reason, it will not be necessary to describe in detail the parts which are commonly used in such systems, such as the keyboard perforator, the transmitters, and printer.

Cipher Machine—Method of Operation

The messages are first punched in a paper tape by means of the keyboard perforator. The code used is shown in Fig. 8. This is the well-known five-unit printing telegraph code. Each letter is represented by a small feed hole and one or more larger holes which may be punched in five different positions across the tape. Since n each of these five positions a hole may or may not be punched, there are $(2)^5$ or 32 possible different combinations in this code of which 26 are used to designate letters, the other 6 representing the so-called "stunts," which are the "space," "carriage return," "line feed," "figure shift," "letter shift," and the "blank" or "idle" signal.

The cipher "key" may take the form of another tape of similar form having characters punched in it at random and with every tenth character numbered, so that the tape may be set to any designated starting position. The key tapes are prepared in advance, the original key being perforated by hand, as by working

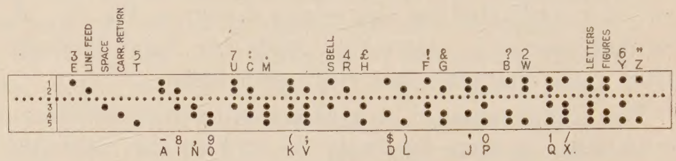

Fig. 8—Tape Showing Printing Telegraphic Code

the keyboard at random, additional copies being made automatically by the machine.

The message tape is passed through a unit known as a transmitter, where the holes in the tape serve to control the positions of five contact levers, each of which makes contact with either of two bus-bars. The key tape controls the contacts of a second tape transmitter. The contacts of the two transmitters are connected to a set of five magnets or relays as shown in Fig. 9. Each magnet wil be energized if the correspondingly numbered contacts of the two transmitters are against opposite bus-bars, but not if they are mak-

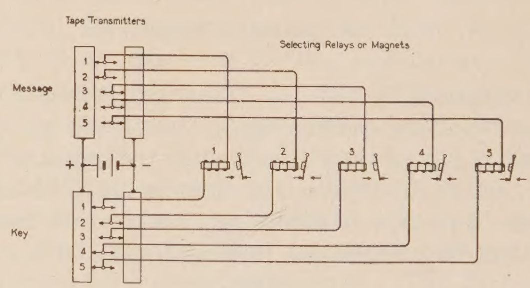

Fig. 9

ing contact with similar bus-bars. In the diagram, contacts 1 and 2 of the message transmitter, are against the left or positive bus-bar, this setting representing the letter *A*. Contacts 1, 4 and 5 of the key transmitter are against the positive bus-bar, representing the letter *B* in the printer code. This will energize magnets 2, 4 and 5, which combination represents the letter *G*.

All of the possible combinations resulting from various characters in the two tapes might be shown in a cipher square similar to that of Fig. 7 except that it would have 32 characters on a side instead of 26.

The characters of the cipher messages, formed in this

way, may be recorded as perforations in a third tape. For this purpose a "machine perforator" is used. This device is similar in many respects to a keyboard perforator and is shown in Fig. 10. The tape, from a reel on the top of the machine, passes through the punch block at the front left corner of the machine. Here it passes under a die plate and over a group of six punches, which may be forced up through the tape by the action of an electromagnetic hammer. Five of these punches are too short to be acted on directly by the hammer and are pushed through the tape only when an individual "selecting finger" is interposed between the punch and hammer. The five selecting fingers are actuated by five magnets which may be controlled by the relays shown in Fig. 9. A ratchet-operated, star-wheel feeds the tape forward after each character has been punched.

The cipher message tape prepared in this way is unintelligible in form and may be sent to the receiving station by messenger or by mail, or if desired, it may

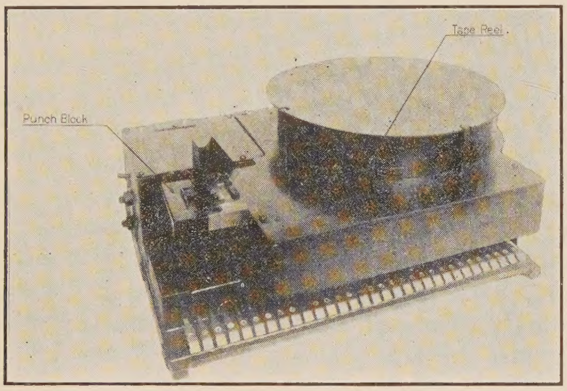

FIG. 10—MACHINE PERFORATOR

be transmitted by wire or radio and reproduced by another machine perforator at the receiving point. The cipher tape is there run through the message transmitter, where its characters combine with those of a duplicate key tape to reproduce the original message, which will be printed out in page form and in "plain text."

LENGTH OF KEY TAPE

With the system as described above, the key tape must be at least as long as the sum of all the message tapes used with it, as the messages will lose their secrecy to some extent if the key tape is used repeatedly. The use of a short repeating key may give sufficient secrecy for some uses however.

A roll of tape eight inches in diameter contains about 900 feet of tape and would serve to encipher about 18,000 words counting five printed characters and a space per word, without repeating the key. If sent at an average speed of 45 words per minute this number of words would require 400 minutes or nearly 7 hours to transmit.

In order to reduce the amount of key tape required for handling large amounts of traffic, the "double key" system was devised. In this system two key tapes are used, the ends of each tape being glued together to form a loop preferably about seven feet in circumference. The tapes should differ in length by one character or by some number which is not a factor of the number of characters in either tape. A separate transmitter is used for each tape, and the characters of the two key tapes are combined, by a method similar to that shown in Fig. 9, with those of the message tape to form the cipher message.

The result is the same as though the two key tapes were first combined to produce a long single non-repeating key, which was later combined with the message tape. This long, single key is not, strictly speaking, a purely random key throughout its length as it is made up of combinations of the two original and comparatively short key tapes. The characters in this key do not repeat in the same sequence at comparatively short regular intervals, however, as would be the case if only one key tape loop were used.

The number of characters in this equivalent single key is equal to the product of the number of characters in the two tape loops, and may easily exceed 600,000 before any part of the key begins to repeat. If proper care is taken to use the system so as to avoid giving information to the enemy regarding the lengths of the two key tape loops or their initial settings and to avoid the possibility of ever re-using any part of the resultant single key, this system is extremely difficult to break even by an expert cryptanalyst having a large number of messages and full knowledge of the construction of the machine and its method of operation.

Captain W. F. Friedman, Cryptanalyst of the Signal Corps, U. S. Army, has recently invented some modifications[5] of this system intended to eliminate the loss in secrecy that results from using the two more convenient comparatively short repeating key tapes instead of the single long non-repeating key tape. These modifications consist of changing at intervals the order of connection of the five contacts of one or more of the tape transmitters or of adding a third key tape and transmitter so arranged that the extra key tape does not step ahead in unison with the other two key tapes, but starts and stops at irregular intervals. Either of these methods, properly used, makes unauthorized decipherment practically impossible and, at the same time, does not unduly complicate the machine or its method of operation.

With the double key tape system, the handling of large volumes of traffic is greatly simplified. The tapes should be numbered so that the deciphering operator can set them at the correct starting point for each message, and rules should be adopted so that both key tapes will never be set twice at the same

5. See Patents 1,522,775 of Jan. 13, 1925 and 1,516,180 of Nov. 18, 1924.

starting point. Information regarding the proper settings for the key tapes for deciphering each message must be sent to the deciphering operator. These settings may be prearranged or they may be selected arbitrarily by the sending operator. In the latter case the numbers representing the key tape settings should be prefixed to the message. These "key indicators" should preferably be enciphered by running them through the machine together with a special key tape which is used only for this purpose.

Speed of Operation

This type of machine was operated by the Signal Corps over its private wire telegraph circuits. In service tests made by the United States Army, each outgoing message was checked by running it again through the machine to decipher and print it, and the deciphered copy was then compared with the original message, so that each message tape was run through

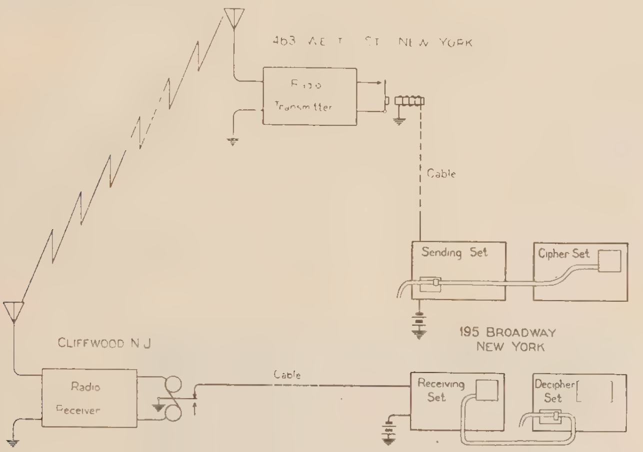

FIG. 11—CIRCUIT FOR RADIO CIPHER DEMONSTRATIONS

twice. A certain amount of time was lost, due to setting and resetting the key tapes, checking, etc., for each message, but an average enciphering speed of 10-15 words per minute was readily maintained. We understand this to be many times faster than those manual methods for enciphering or coding, which are used where a high degree of secrecy is required. Incoming messages were deciphered at the rate of 30-40 words per minute.

Operation by Radio

This cipher system was demonstrated before the delegates to the Preliminary International Communications Conference in October, 1920. During this demonstration, cipher messages were sent over a circuit containing a radio link, as illustrated in Fig. 11. The radio equipment was the same as that employed a year previous in tests on the operation of multiplex and start-stop printing telegraphs by radio and is described elsewhere.[6]

A considerable number of cipher messages was transmitted over this radio circuit during this demonstration, these messages being automatically enciphered before and deciphered after transmission, so that they they were absolutely secret, even though transmitted by radio. No interference from atmospherics or from other radio stations was noticed, all messages being received without error.

In conclusion, we wish to express our appreciation of the assistance given us by the officers of the Signal Corps and the General Staff, of the United States Army, in making tests and trials of cipher printing telegraph systems; and we wish particularly to acknowledge our indebtedness to Lt.-Col. J. O. Mauborgne, of the Signal Corps, for his advice in connection with this development and for his assistance in arranging to have tests made to determine its secrecy and demonstrations and service trials to determine its practicability for Army use. We also wish to express our appreciation of the services rendered by the Cipher Department of the Riverbank Laboratories, Geneva, Illinois, and by Col. George Fabyan, the head of these laboratories, in making tests of the secrecy of messages enciphered in various ways with these machines.

DIELECTRIC PHENOMENA

An important contribution to the study of dielectric phenomena in electric cables was made by Capt. P. Dunsheath in a recent I. E. E. paper. Developing a theory first propounded by Clerk Maxwell, the author showed how, without any hypotheses regarding the molecular structure of a dielectric, the familiar absorption effect can be explained by the lack of homogeneity of the dielectric. In such a dielectric the ratio of capacities of adjacent layers will not be identical with the inverse ratio of their resistances. The potential distribution due to the capacities will, then, differ from that due to the resistances. The latter distribution being the one obtaining when the steady state is reached, compensating capacity currents have to flow into the various condensers to adjust their potentials to the required values. The circuit for these currents consists of capacity in series with a very high resistance; they will therefore follow an exponential law and persist for a considerable time. The charging current of a cable subjected to a steady potential consists, accordingly, of three parts, the initial rush giving a potential distribution corresponding to capacity, a steady leakage current, and a transient current which gives the final potential distribution. Developing this theory, Capt. Dunsheath gave a simple explanation of the well-known V curve connecting A. C. dielectric loss with temperature, based on the negative temperature coefficient of electrolytic conductors. Although the difference between the Maxwell and the molecular theories may be purely verbal, the advantage of the former cannot be questioned, as giving a clearer insight into the electrical properties of dielectrics, and marking an advance towards the more perfect knowledge which will enable dielectric phenomena to be subjected to exact calculations.—*World Power*, December, 1925.

6. "Printing Telegraph by Radio" by R. A. Heising, *Journal of the Franklin Institute*, January 1922, pp. 97-101.

Supervisory Systems for Electric Power Apparatus

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Member, A. I. E. E.

Synopsis.—A general survey and description of the various types of supervisory systems for control and indication of remotely located electrical apparatus is given in the paper, the author first of all comparing the better known remote-control system with the supervisory system in general practise today. Description is given of the selector, distributor, audible, code-visual, synchronous-relay-visual and the carrier-current systems, the principles and features of each being discussed. The subject of telemetering is also included, together with an expression of the author's ideas of future possibilities for each of the systems above enumerated.

Introduction

SUPERVISORY systems for the control and indication of remotely located electric power apparatus can best be introduced by comparing them with the better known and more widely applied remote control systems in general application today.

The usual remote control scheme employs at least one continuous individual metallic connection between each device to be controlled and the controlling switches or keys. Supervisory systems use no individual and one, two, three or more common metallic connections between the devices to be controlled and the controlling switches or keys for as many as fifty or sixty or even more devices. Remote control systems ordinarily use control currents of the order of magnitude of one to ten amperes. Supervisory systems usually use currents of the order of magnitude of three to ten milliamperes. Remote control systems require a definite and usually very short time interval to elapse between the closing of the control switch or key and the closing of the contacts at the remote point. Supervisory systems require an appreciable and variable time to elapse between the operation of the control switch or key and the closing of the contacts at the remote point. Remote control schemes are usually designed into the electrical operating sequence of the power apparatus. Supervisory systems are invariably superimposed upon the usual sequence. Briefly, supervisory systems provide improved means for the supervision of electric power transmission and distribution.

History

Supervisory systems were developed to meet the requirements of the railway and central station industries as these expanded. The grouping of generating stations under the direction of a centrally located load dispatcher made it desirable that the dispatcher have prompt and accurate information concerning the electric power system. The widespread application of automatic switching to railway substations made it important that the power director have immediate and correct information in regard to his substations at all times.

One of the first supervisory systems was installed between the Sherman Creek Station of the United Electric Light & Power Co. at 201st Street and Broadway, New York City, and the load dispatcher's office of the New York Edison Co. at 38th Street and First Avenue, New York City in 1915. It used a form of step-by-step selector relay developed about that time for automatic telephone application. It gave indication at the dispatcher's office of the open and closed position of about one hundred oil circuit breakers using a total of six wires between the generating station and the load dispatcher's office.

The next step was made when the Receiver of the Des Moines City Railway expressed a desire for some means of isolating his automatic railway substations in case of an emergency such as a fire or an accident. This demand was met by the development of the selector supervisory system and followed promptly by the development of the distributor supervisory system. Next in order came the code visual, the audible, the synchronous relay and lastly the carrier current supervisory system. Beside these, developed and standardized by the manufacturing companies in this country, there has been a number of systems developed by the employees of many corporations not only in the railway field but also in the central station and industrial fields. These, however, have usually been limited to a definite field of application and have not been extended to become a commercial article of trade.

Selector

The selector system was the first one developed for commercial application which is still on the market. It uses the essential elements of the telephone train dispatching call system modified for the control and indication of remote electric power apparatus. An installation made in 1920 is still in active service.

A key, a selector, some indicating lamps, and three line wires form the essential elements. The key when turned and then released makes and breaks an electric circuit through two of the wires to which all of the selectors in the outlying stations are connected in multiple. The key in operating sends out a predetermined number of electric impulses spaced in a definite time sequence thus forming a code. The selectors are provided with contacts mounted so as to make an electric circuit when a ratcheted wheel moves a given number of steps. The code sent out by the key starts all of the selectors simultaneously.

1. Engineering Dept., General Electric Co., Schenectady, N. Y.

To be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926.

Only that selector, however, which is arranged to respond to the code sent out by the key closes its contacts. The other selectors drop out successively as the code being sent fails to give their combination. Thus, there is usually one hand-operated key at the controlling station for each selector contact at the outlying station. For the return indication

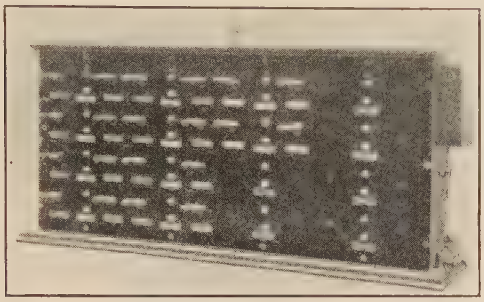

Fig. 1—Lamp and Key Case for Dispatcher's Office of Selector Supervisory System

there is provided at the outlying station a motor operated key for each group of four or less pairs of functions at that station to be indicated. Upon the operation of any supervised device in an outlying station, auxiliary contacts upon it start the motor key. This then sends back to the controlling station a code

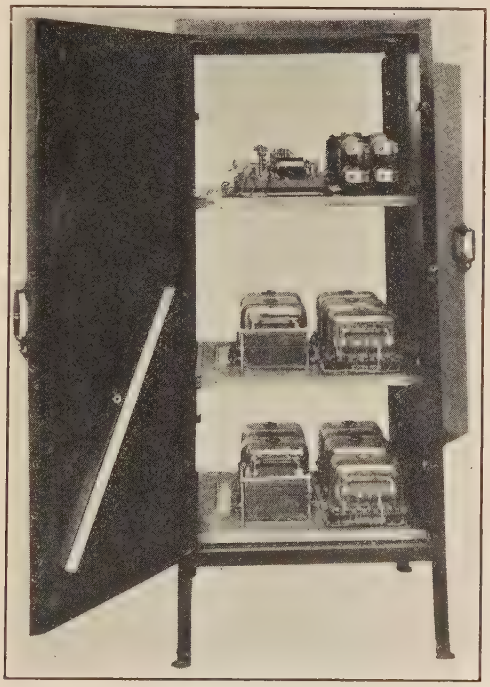

Fig. 2—Sending Apparatus in Cabinet of Selector Supervisory System

similar to that sent out from the controlling station to perform an operation. The selector located at the controlling station which is set to close its contacts upon the receipt of the code operates indicating lamps to show the position of the device supervised.

All of the outlying stations of a selector supervisory system are connected to one controlling station by three line wires. At each outlying station, the equipment is multipled to two of the wires as they pass by while the third wire loops into each station. The two wires as before mentioned are used for sending out the code for causing an operation to be performed and for transmitting back the code which results in giving an indication by lamps of the position of the equipment supervised. The third wire is used to lock out all the stations connected to the system excepting the one being controlled or the one sending in a code for causing an indication to be shown.

An arbitrary maximum of fifteen outlying stations may be connected by the usual selector systems to the controlling station. Each outlying station may have a maximum of eight devices to be supervised if there are as many as fifteen stations, or if there are fewer, each

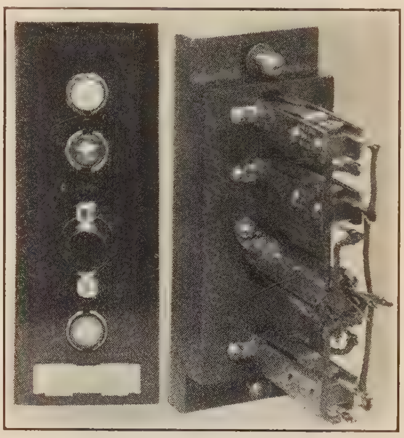

Fig. 3—Lamp and Key Unit for Distributor Supervisory System

outlying station may have a maximum of twelve or fifteen. The maximum number of devices, however, which can be most economically supervised by a single selector system depends largely on circumstances but under present conditions should never exceed fifty or sixty.

The selector system requires about nine seconds to send out each code, and complete an operation. Therefore, if ten outlying devices were to be operated it would take about one and two-thirds minutes to send out the code and operate these devices.

Distributor

The distributor system was the next type of supervisory system to be developed. It is an adaptation of the automatic printing telegraph in commercial use today on practically all the principal telegraph circuits. An installation of this type of supervisory system made in 1921 is still in active service.

A key, a distributor, a polarized relay, some indicating lamps, and four line wires form the elements. The key is usually a two-position one and is the equivalent of a double-throw switch. When turned to either

position it makes a circuit between a common wire and either the positive or negative side of a source of power and a segment on the distributor. The distributor consists essentially of three sets of coaxial segments insulated from each other. Each segment of one set is connected individually to its control key. Each segment of the second set is connected to the coil of a two-position polarized relay which is

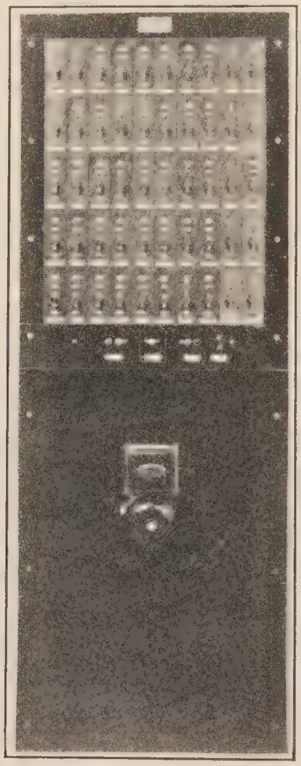

Fig. 4—Panel Containing Lamp and Key Units

For the control and indication of fifty circuit breaker equivalents in distributor supervisory system

associated with the appropriate indicating lamps. A set of segments midway between these two is used for synchronizing the distributor in the outlying station with the distributor in the dispatcher's office, synchronism being checked each five segments or ten times per revolution.

The distributors are each provided with three sets of brushes which rotate over the coaxial segments and make connections successively between each individual segment and a continuous segment in each set thus permitting a momentary electric circuit to be made through the distributor. The brush arms of each distributor are driven through a reduction gearing by a direct-current motor from a trickle-charged storage battery and are provided with a centrifugal governor for maintaining constant speed within quite narrow limits. The brush arm has a speed of about twelve rev. per. min.

At the controlling station are located the control key, indicating lamps, one distributor for each group of fifty or less devices to be supervised, and one relay for each device to be supervised, as well as suitable battery or other power equipment. At the outlying station are located a similar distributor for each group of fifty or less devices to be supervised in that station, one relay for each device to be supervised and the necessary battery or other power equipment.

The system operates continuously. This means that the positions of all devices which are supervised are automatically checked twelve times per minute or once each five seconds. Should any device change its position the change is indicated at the controlling station within five seconds of the time the operation has occurred. If several devices or the entire group connected to the system change position simultaneously, the lamps at the controlling station will give correct indication of the new position within five seconds of the time the change has occurred. Besides, the workability of the system is indicated continuously in much the same manner as the pulse indicates the general health of a human being.

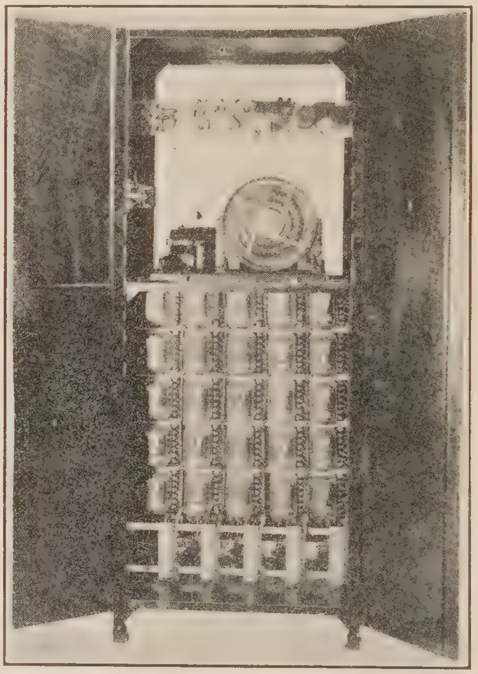

Fig. 5—Relay and Distributor Cabinet

For control and indication of fifty circuit breaker equivalents in the distributor supervisory system

To open or close an oil circuit breaker or perform any similar function it is merely necessary to turn first one key and then a master key. This changes the polarity of a segment on the distributor at the controlling station and within five seconds momentarily energizes a corresponding segment on the distributor at the outlying station. This causes the position of the polarized relay connected to that segment at the outlying station to change in accordance with the impulse sent out from the controlling station and the operation desired is performed. Immediately the operation is completed auxiliary switches on the device supervised

change the polarity on an associated segment on the distributor at the outlying station. This, within a maximum time of five seconds, changes the polarity of a corresponding segment on the distributor at the controlling station which in turn changes the position of associated polarized relays located there. The relays then change the lamp combinations to indicate the new positions of the devices supervised at the outlying station.

Audible

The audible system is an adaptation of the automatic telephone being applied in many large and small telephone systems today. Its essential elements are a dial, a telephone line, telephone lamps, selectors and a

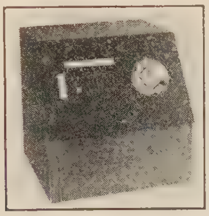

Fig. 6—Dispatcher's Sending Station for Westinghouse Audible Supervisory System

receiver or loud speaker. Operation is secured by dialing as in calling a number by an automatic telephone. The first dialing selects the station to be supervised, it being possible to connect as many as six to a single controlling station by a single pair of tele-

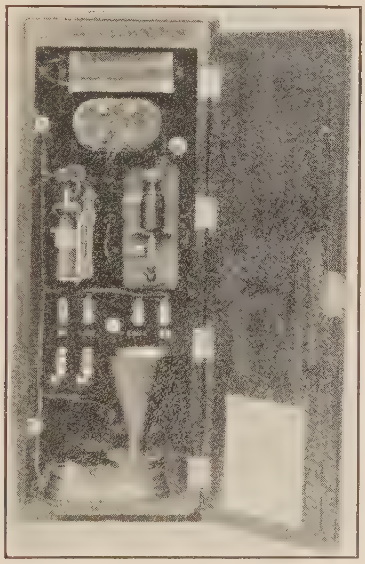

Fig. 7—Dispatcher's Sending Cabinet for G. E. Audible System

phone lines. The stations not selected are locked out by the operation of suitable devices in their equipment.

The station selected sets up a series of impulses indicated at the controlling station by a series of tones in code through a receiver or loud speaker located at that point.

The next dialing causes the desired operation to occur in the outlying station by setting up a suitable path in a relay combination finally closing the contacts of an operating relay. When the operation directed has been performed, auxiliary contacts on the device actuate other relays which in turn set up impulses indicated at the control station by a series of tones in code as before.

Code Visual

The code visual system is similar in principle to the selector system but differs quite markedly in its detailed design. It consists essentially of a key, with

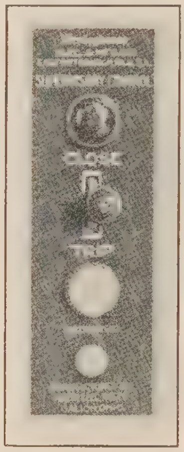

Fig. 8—Lamp and Key Unit
For code visual supervisory system

its associated lamps, groups of relays at the controlling station and similar groups at the outlying station. It uses two common wires between the control station and all of the outlying stations and in addition one

Fig. 9—Dispatcher's Lamp and Key Cabinet
For code visual supervisory system

individual wire from the controlling station to each outlying station. Thus, if there were three outlying stations, there would be five wires starting from the controlling station and running to the first outlying station, four running to the second outlying station and three to the third outlying station.

An operation is performed by moving a three-position key to either of the two extreme positions. This com-

pletes an electric circuit which causes groups of relays at the control station to send out a code of successive impulses. These impulses select suitably coded groups of relays at the outlying station. If the code is not received correctly at the outlying station, the controlling station then again starts the code out and continues to send it at intervals until correct code is received at the outlying station. If the code, however, is repeated correctly at the outlying station, then an impulse is sent out from the controlling station which causes the operation desired to be completed.

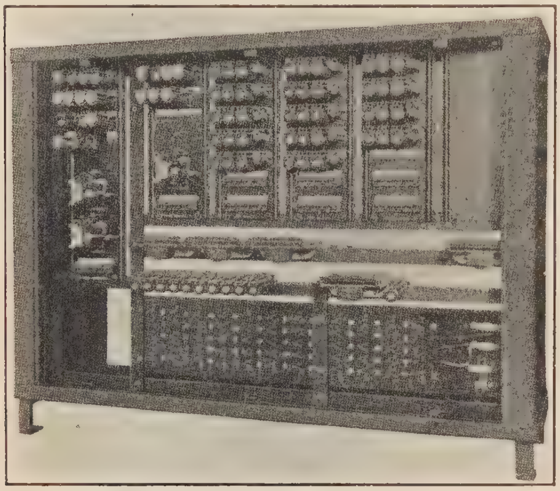

FIG. 10—RELAY EQUIPMENT IN DISPATCHER'S OFFICE
For code visual supervisory system

When the operation of a supervised device has occurred an auxiliary switch connected to it causes a code to start from the outlying station. This is formed and transmitted to the control station in the same fashion as is the operating sequence from the controlling station. When the correct code is checked the lamp signals at the controlling station are changed to indicate the new position of the supervised device.

This system operates devices successively and it requires about nine seconds per device to cause a series of operations. If, therefore, ten devices were to be operated it would take about ninety seconds to operate the devices.

SYNCHRONOUS RELAY VISUAL

The synchronous relay visual supervisory system is an all relay system which uses the principle of step-by-step synchronous selection. It consists essentially of a two position key with its associated lamps, a start key and relays in the controlling station, four wires between the controlling station and the outlying station, and relays in the outlying station.

When an operation is to be performed, the two-position key is turned from the position it occupies to the other position and the start key is pushed. This immediately causes a simultaneous operation of relays in the control station and the outlying station until the point is reached in the sequence in the outlying station corresponding to the position of the key in the controlling station. Operating current then passes through the signaling circuit from the control station to the outlying station and causes the desired operation to be performed. When the device supervised has had its position changed, auxiliary contacts on it transmit a return signal in a similar fashion to the controlling station causing the lamps located there to change in accordance with the changed position of the apparatus in the outlying station.

Two of the four wires between the control station and the outlying station are used for keeping the signaling relays at the two stations in step as they are moved from point to point in a definite sequence. The other two wires are switched by the operation of these relays from one device to another as occasion demands to cause operation or indication of that device.

CARRIER CURRENT

Carrier current has been developed for use with the selector and code visual systems. Both systems use codes of impulses for causing an operation to be performed and for causing an indication of that operation to be registered. The carrier current equipment consists of the necessary tubes, reactors, condensers and resistors for generating high frequency at the controlling and outlying stations.

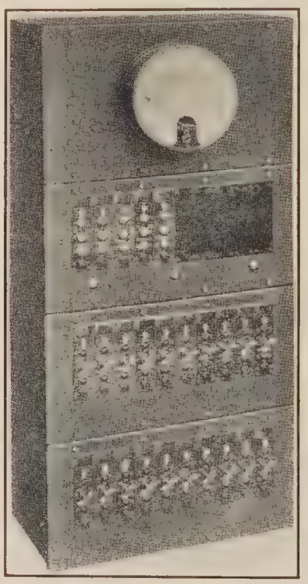

FIG. 11—CABINET CONTAINING LAMP AND KEY UNITS AND AMMETER
For the control and indication of three circuit breaker-equivalents by the synchronous relay supervisory system

In general, the code is transformed from pulsating alternate polarity impulses to high frequency impulses and is transmitted over one line and ground or a pair of lines which may at the same time be used for communication or power transmission purposes. The carrier current equipment is connected to the transmission circuit by a condenser or other suitable coupling.

Carrier current for use with supervisory systems takes the place of the special line wires required where direct-current impulses are employed. It permits the use of practically the same equipment, so far as the controlling station and outlying stations are concerned as is used for direct-current. The only difference is that where direct-current is employed, special line wires are required, while where carrier current is employed, any existing wires can usually be used.

Wireless

Wireless has been considered for use with supervisory systems but to date no commercial development or application is known by the writer. The art seems not yet to have developed sufficiently.

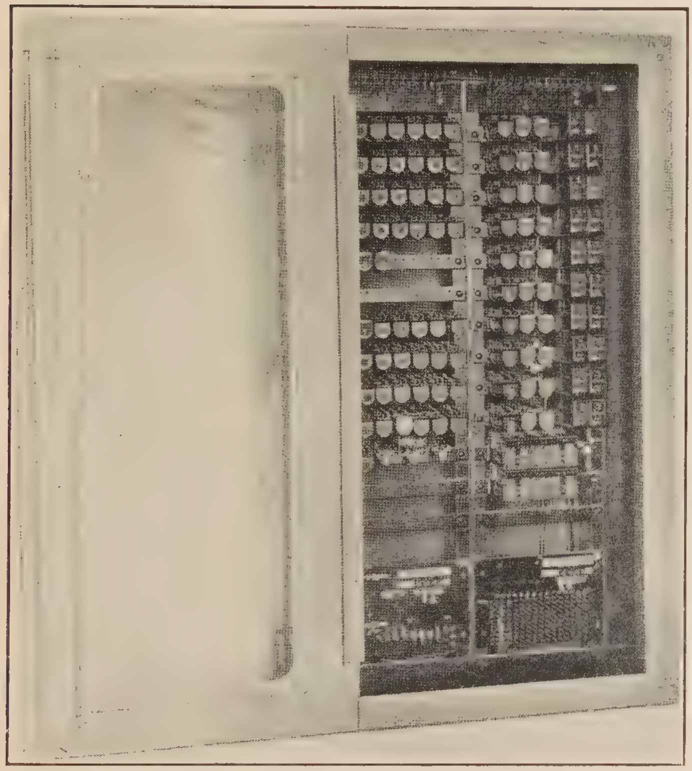

Fig. 12—Relay Cabinet for Dispatcher's Office, Synchronous Relay Supervisory System

Control Station

The control station equipments provided for the various types of supervisory systems which have been described vary one from another.

The selector system uses two keys, one to perform a closing or similar operation, the other to perform an opening or opposite operation. The key is quite similar to that used in the call stations of the Western Union Telegraph Company. The key is turned but nothing happens in the external circuit until it is released. The turning of it winds up a helical spring. As soon as the key is released the helical spring rotates it in the reverse direction under the control of a fly ball governor in order to obtain practically constant speed. In rotating back to its original position it opens and closes contacts in a definite sequence. If these contacts are suitably connected in an electric circuit they thereupon form a code of successive impulses.

As before stated two keys are required for each pair of functions. Associated with these two keys are two telephone lamps, capped with suitable lenses. These indicate the open or closed position of the device supervised. In place of indicating the position of a device if it is desired to indicate the position of water level or the position of a gate then the lamps only are used and as many of them are employed as positions to be indicated are desired.

The distributor system uses a combination of three telephone lamps and one two-position key to obtain control and indication. The two position key performs the same connections as a single pole double throw switch having no mid position. Associated with it are three telephone lamps. One is capped with a red lens, one with a green lens and one with a white lens. The red and green capped lamps indicate the closed and open position of the device supervised or any other indication usually desired. The white capped lamp is lit only during the time that a function has been called for and is put out immediately after that function has been completed and a return indication showing the completion of this function recorded at the controlling station. It is also lit should a device supervised at the outlying station automatically change its position, in which case it remains lit until the key in the controlling station is turned to acknowledge the operation at the outlying station. For each group of fifty two-position keys with their associated lamps there is one master key. The master key is turned after the two-position keys have been placed in the positions corresponding to the one which it is desired that the outlying supervised devices take.

The audible supervisory system employs a dial similar to that used for automatic telephones. In one commercial scheme, this dial is identical with that used for automatic telephones; in another commercial scheme this dial is similar but has had its speed altered to make it correspond to that of the selectors used. No lamps are used with the audible system, the operator depending upon hearing certain code tones in a receiver or loud speaker for indications.

The code visual supervisory system uses a three-position key associated with three telephone lamps capped by red, green and white lenses in much the same fashion as does the two-position key with its associated lamps in the distributor system.

The synchronous visual supervisory system employs a dispatcher's equipment consisting of a two-position key, a locking-type push button and three-telephone lamps capped by red, green and white lenses. The two-position key is to fix the operation while the push button is to stop the synchronous relay control equipment at any point.

Various methods have been employed for mounting the controlling lamps and keys. They may be placed on vertical panel boards, set into desk tops or even placed in a system diagram. The mounting best suited for any particular application depends to a large measure upon the individual requirements.

Application

The application of supervisory systems to any existing or new electric power transmission or distribution systems requires careful study in order that a maximum benefit may be derived. It is necessary to know intimately the method of operating the network of lines, feeders, and machines as well as the electric power traffic requirements. For congested districts where an emergency may at times require the rapid re-establishment of service, the speed of operation of a supervisory system is quite essential. On interurban railway projects, however, where automatic substations are located at intervals along a narrow strip of territory and where there are only three or four devices or functions to be supervised in each station, speed is not as important as line maintenance so another type of supervisory system is usually chosen. In some cases, the revenue derived from a station warrants only the most inexpensive supervisory system. Hence, here would be a place for the so-called audible type where the operator checks manually and at intervals determines by sound the condition of the equipment in the outlying station. Again, on a high-tension transmission system where distances often exceed one hundred miles the carrier current supervisory system is the best choice.

In applying supervisory systems it must be clearly borne in mind at all times that they are quite different in their performance as contrasted with the usual types of remote control systems. Each has its limitations. Remote control systems are in general limited to distances of several miles while the supervisory systems may be used for distances up to several hundred miles. Supervisory systems require an appreciable time interval averaging about five seconds for the completion of an operation through their medium while remote control systems operate practically instantaneously. So in applying supervisory systems, care must be exercised to take into account all of the electric power system characteristics as well as the limitations of the supervisory system.

Installation

The correct installation of a supervisory system is quite as important as its selection if the best results are to be obtained. Supervisory systems use currents of telephonic magnitude while remote control systems use currents of power magnitude. Hence, insulation and current leakage require very careful attention for the successful installation of a supervisory system, telephone practise being the standard toward which the installation of these systems must tend. The steam railroads have recognized these requirements when installing the selector type telephone train dispatching call system. More and more of them are going to the higher grade lead-covered paper-insulation telephone cable for their train dispatching circuits. The same cable and the same type of insulation are generally recommended as best practice for supervisory system installations.

Checking

Supervisory systems from a checking standpoint may be classified into two groups. One group requires checking at intervals, the other group is automatically checked at intervals.

All systems excepting the distributor system require manual checking at intervals. The distributor system has a distinct advantage in that it automatically checks the position of all of the devices connected to it at frequent intervals besides indicating its readiness to serve continuously.

Maintenance

The maintenance of a supervisory system depends upon its initial design and installation. All supervisory systems may for this comparison be divided into two classes. One class uses telephone relays and auxiliaries throughout. The other class uses telegraph relays and similar devices throughout.

The telephone relays and devices have been designed with the fundamental idea that someone would be present not only at the subscriber's station for operating the equipment but also at the central office for supervising and constantly inspecting the equipment. This results in a tacit assumption by the designers that if anything should go wrong either the subscriber or the wire chief or operator would detect the fault and correct it, no harm being done excepting possibly an interruption of service from one subscriber's station. Such relays particularly require inspection at least daily in order that the best results may be obtained with them.

The systems using telegraph devices may be typified by the selector system. Here the devices are large and substantial and so designed as not to require attention for years at a time. To be sure, there is quite a difference in the cost of the individual devices since the telegraph devices are made in very much less quantity than are the telephone devices. Contrasted, however, one with the other is the fact that the telephone type of devices require more maintenance and adjustment than do the telegraph devices.

Protection

Supervisory systems operating over special wires require protection particularly where these wires are subjected to lightning, inductive and similar high voltage disturbances. In general, isolating transformers or drainage coils cannot be used because these transformers would interrupt the flow of signals and the drainage coils would drain off the signal current. So

far as is known the best type of protection is for the conductors to be placed in cables. For this purpose paper-insulated lead-covered cable having an insulation which will withstand 1000 volts between conductors and 3500 volts between conductors and lead sheath is usually recommended.

The question of protection is an active one at the present time and many of the operating companies as well as the manufacturers would be interested to hear what other operators are doing to maintain their supervisory systems with a maximum of protection and a minimum of interruption.

Telemetering

A discussion of supervisory systems would not be complete without brief mention being made of telemetering. Telemetering furnishes the concluding link in the development of the art of supervising remotely located power apparatus.

Telemeters have been developed for transmitting the readings of ammeters, voltmeters, watthour meters, wattmeters and power factor meters over telephone lines the same distance as supervisory systems can be operated. They use practically the same type of relays at the originating and receiving ends of the telephone lines and in certain designs it has been found possible to combine the telemetering and supervisory functions on the same wires. In one particular installation recently made, two incoming lines, two synchronous converters and nine feeders were controlled and indicated and the readings of two watthour meters transmitted back to the controlling station, all over two pair of telephone lines between the controlling station and the outlying station. This is not a limiting number of things which could be done over these four wires but represents only about one-third of the functions and readings which could have been obtained if desired.

Future

Supervisory and telemetering systems are just about being recognized by the engineering public. They are relatively new although a number of installations are now in operation. Nevertheless, it is believed that only an initial advantage has been taken of them and that they are not yet as thoroughly a part of electric power transmission and distribution engineering as are transformers, turbines, and the more commonly accepted pieces of electrical apparatus.

It is my firm belief that supervisory and telemetering systems in combination with automatic stations represent as distinct an advance in the electric art as has the development of the automobile in the transportation problem. It is also believed that a very great change will be effected in electrical engineering practise during the next ten years as a result of the economic application of supervisory and telemetering systems.

FLUX IN A CIRCULAR CIRCUIT

By Carl Hering

Fellow, A. I. E. E.

The flux density, H, at the center of a circular circuit of one turn is known accurately to be $2\,\pi\,i/r$; in fact, it has been made the quantitative connecting link between current and magnetism and the basis of the ampere. But the H in any other part of the circle is very difficult to calculate as it involves elliptical integrals, and to integrate these for getting the total flux is almost hopelessly complicated and then at best only approximate.

The density at any point outside of a single, straight, conductor (one far removed from its return) is definitely known to be $H = 2\,i/r$, and the total flux around any length l and radius a, up to any radial distance r, is also known definitely to be $F = 2\,l\,i\log_e(r/a)$. This, however, does not include the flux inside of the wire.

By calculating the total flux in a circular circuit indirectly from Kirchhoff's well-known, though only approximate, formula for self-inductance, $L = 2\,l\,(\log_e(l/a) - 1.508)$ in which a is the radius of the wire, and l the length, the author found, over extremely wide ranges of the radius r (a being constant),

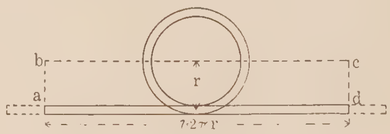

Fig. 1

the interesting result that the total flux in a circle of radius, r, seems to be equal to that around a length, l, of single, straight, conductor of equal length (that is, equal to the circumference of the circle) and up to a distance r from the axis, that is, to that in the rectangle $a\,b\,c\,d$.

There is a small, though constant, difference (always greater for the circle) due undoubtedly to the flux inside of the wire, which is included in the formula for the circle but not in that for the single conductor; these lines have only a fractional effect in the induction. The agreement is of the kind that strongly indicates that this equality would probably be found to be theoretically exact for the same size of wire if the theoretically definite value of the flux in a circle could be found; when a result is indicated or known, a proof is sometimes more easily found. Such being the case, the total flux in a circle could be expressed by a simple, theoretically exact, definite formula, independent of the self-inductance, and the latter checked by it, so far as quantity of flux is concerned.

Had our forefathers, in formulating our units, adopted as their fundamental the single conductor instead of the circle, the factor π would have dropped from some of the present fundamental relations.

The Ratings of Electrical Machines As Affected by Altitude

BY CARL J. FECHHEIMER[1]

Fellow, A. I. E. E.

Synopsis.—*The paper contains equations applicable to machines cooled by forced air convection currents. It is to be hoped that the A. I. E. E. Standards Committee will find some helpful suggestions in the paper.*

Ignoring differences in ambient temperature, the effect of altitude may be considered from two standpoints:

(a) The change in temperature rise, the rating remaining the same; or (b) the change in rating, the temperature rise at a given altitude equaling that at sea-level. The applications of both are considered, and equations are solved in both ways. The difference in ambient temperature at sea-level and at altitude is also taken into consideration in other equations.

The present A. I. E. E. rule is known to be faulty, applies only on the basis of temperature change, and starts at 1000 meters. These and other objections are believed to be met in this paper.

Several of the equations are plotted in families of curves, which should be of assistance to the reader. By assuming other values for some of the factors, other similar curves can be drawn.

In Appendix I, the derivations of equations are given. Appendixes II and III cover discussions of two of the factors used in the equations. In Appendix IV, some cases other than a slotted core are discussed.

A number of assumptions were made in the derivations of the equations: (1) The temperature coefficient of resistance was neglected. (2) The heat that flows transversely through the insulating wall is the same percentage of the heat generated in the copper at altitude as at sea-level. The equations are intended to apply to a slotted core, although they may be used for other parts of an electrical machine. Some examples are given in Appendix IV.

* * * * *

It has long been known that the density of a gaseous cooling medium influences the rate at which heat is dissipated from a heated surface, and at the February 1913 Convention of the American Institute of Electrical Engineers an attempt was made to correlate the temperature rise of an electrical machine with the barometric pressure. The revised A. I. E. E. standardization rules of December 1914 contained a statement for correcting temperature rise or rating to correspond to higher altitude, but the rule was intended only to be temporary, and it is now recognized as faulty. Several articles on this subject have recently appeared in the *Technical Press*[2] and in this article another method of attack is presented. It is to be hoped that the A. I. E. E. Standards Committee will find some helpful suggestions herein.

If the change in ambient temperature is ignored, it is evident that the effect of altitude may be considered from two standpoints: (a) The change in temperature rise, the rating remaining the same; or (b), the change in rating, the temperature rise at a given altitude equaling that at sea-level. Perhaps the most usual case, in which the purchaser of apparatus is interested, is how much less the temperature rise of the machine should be at sea-level than at a given altitude for the same load. The machine usually is tested near sea-level, and the customer wishes to know how much to decrease the test temperature rises to equal approximately those at the higher altitude. This is the most useful way for the correction to appear in the A. I. E. E. Standards. It is well, however, to include another method to cover the change in permissible output with altitude for operating recommendations. Equations in this form should also be of value to the designing engineer, as with their use he can tell how much the rating of a machine should be altered if transferred from sea-level to a higher altitude.

In the 1925 A. I. E. E. Standards, the rule reads: "For apparatus intended for service at altitudes greater than 1000 meters, it is provisionally agreed that the permissible temperature rises (to be included in contracts and checked by test at low altitude) shall be less than specified in these standards by one per cent of the specified rise for each 100 meters of altitude in excess of 1000 meters." The "Usual Service Conditions" are given as "(a) When and where the temperature of the cooling medium does not exceed 40 deg. cent. (b) Where the altitude does not exceed 1000 meters."

From the above it will be seen that in the existing A. I. E. E. rules:

(1) The correction for altitude is only on the basis of temperature change, not on a change in rating.

(2) The correction for altitude starts at 1000 meters, there being no correction for altitudes lower than that elevation.

(3) The correction for altitude is in very simple form, and as such cannot possibly bring in the various factors upon which such correction depends.

(4) The correction for altitude is empirical, and is based upon a limited amount of data; it is consequently liable to be considerably in error.

It is believed that these objections are met in this article. The derivation of the equations are given in Appendix I. The final equations may be put into various forms, according to what the point of interest is, what items are to be considered and what ones are to be ignored. They may be classified according to whether the solution is for temperature or for rating.

1. Research Engineer, Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa.

2. Particularly the paper by Doherty and Carter: "Effect of Altitude on Temperature Rise," TRANS. A. I. E. E., 1924, p. 824.

To be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926.

The solutions are applicable to forced convection conditions only. The equations are intended to apply chiefly to a slotted core, in which some of the losses are constant, and some are proportional to the square of the load. The factor k is the fraction of loss in the core that is proportional to the square of the load at sea-level rating. (Thus, in estimating k, the numerator is the embedded copper loss, and the denominator the embedded copper loss plus the core loss). For the more usual applications of the equations 1 and 2 below, k fortunately does not appear. The equations can be applied to other parts than the slotted core, such as field coils in synchronous alternators, but then, although $k = 1$ and the equations are therefore simplified, account must be taken of the rate at which the field current changes with the load, and that is beyond the scope of this paper. In Appendixes II and IV, k and cases other than a slotted core are briefly discussed.

The final equations are as follows: (The list of symbols follows the equations.)

(a) Solutions for temperatures:

I. Surface temperatures only considered.

$$\frac{\theta_{s1}}{\theta_{s2}} = \left(\frac{B_2}{B_1}\right)^m \tag{1}$$

II. Internal (copper) temperatures considered:

$$\frac{1}{b} = \frac{\theta_1}{\theta_2} = \frac{1}{a + (1-a)\left(\frac{B_1}{B_2}\right)^m} \tag{2}$$

(b) Solution for Ratings.

I. Surface temperatures only considered.

1. Permissible temperature rise at a given altitude the same as at sea-level.

$$K = \sqrt{1 - \frac{1}{k}\left[1 - \left(\frac{B_2}{B_1}\right)^m\right]} \tag{3}$$

2. Permissible temperature rise at a given altitude different from that at sea-level:

$$K = \sqrt{1 - \frac{1}{k}\left[1 - b\left(\frac{B_2}{B_1}\right)^m\right]} \tag{4}$$

II. Surface drop and drop through insulation considered.

1. Permissible temperature rise at a given altitude the same as at sea-level.

$$K = \sqrt{\frac{1 - (1-k)(1-a)\left(\frac{B_1}{B_2}\right)^m}{a + k(1-a)\left(\frac{B_1}{B_2}\right)^m}} \tag{5}$$

2. Permissible temperature rise at a given altitude different from that at sea-level:

$$K = \sqrt{\frac{b - (1-k)(1-a)\left(\frac{B_1}{B_2}\right)^m}{a + k(1-a)\left(\frac{B_1}{B_2}\right)^m}} \tag{6}$$

In the above equations,

a = ratio of the thermal drop from the copper to the iron to the total temperature rise, at sea-level.
b = ratio of the total temperature rise at a given altitude to the total temperature rise, at sea-level.
B_1 = barometer reading at sea-level.
B_2 = barometer reading at a given altitude.
k = fraction of loss in the core that is proportional to the square of the load at sea-level rating.
K = fraction of sea-level rating that should apply at a given altitude.
m = exponent of barometric pressure ratio, and is the power to which that ratio should be raised to determine how much the surface temperature rise is altered by a change in density. Its value is between 0.75 and 1, and for most purposes 0.9 may be used.
θ_1 = total temperature rise at sea-level.
θ_2 = total temperature rise at a given altitude.
θ_{s1} = temperature rise of the cooling surface above the ingoing air, at sea level.
θ_{s2} = same as θ_{s1}, but at a given altitude.

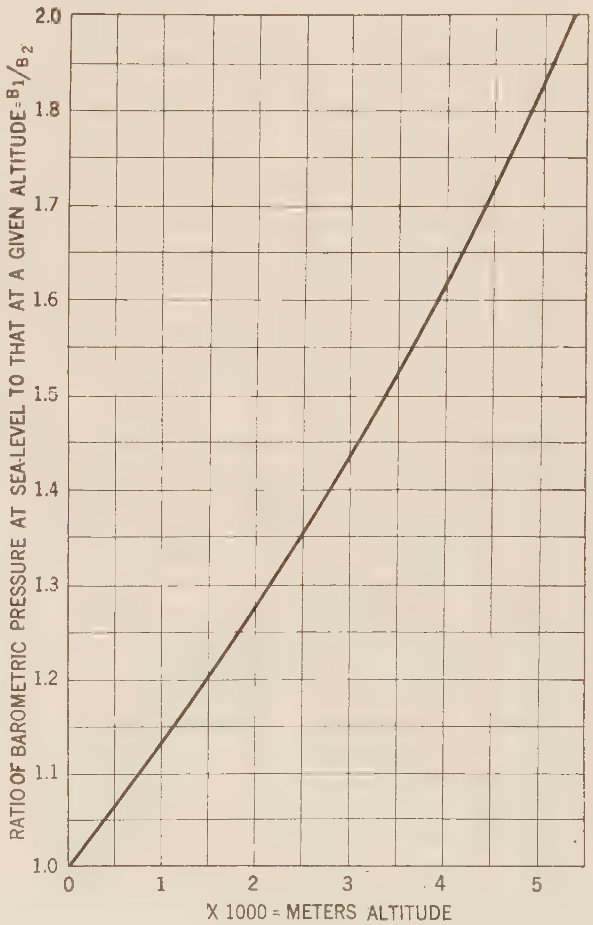

Fig. 1—Curve of Barometric Pressure

In Fig. 1 is plotted the ratio of the barometric pressure at sea-level to that at a given altitude. With these data, and that contained in equation (1), the curves in Fig. 2 have been plotted. They show what the ratio of the temperature rise at sea-level to that

at altitude should be, outside surface temperatures only being considered. They are plotted for three different

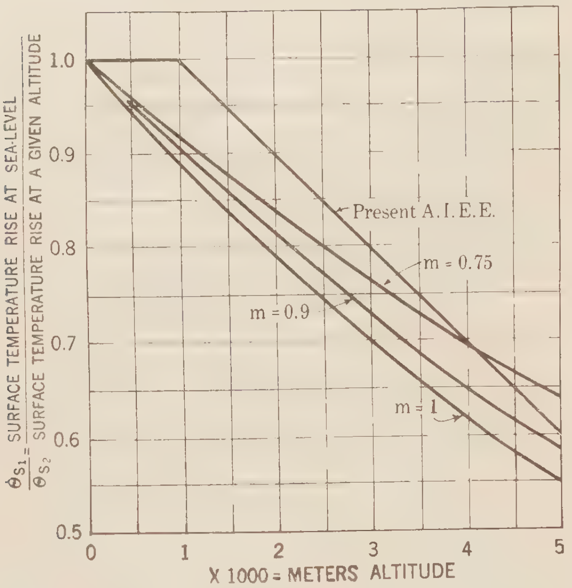

FIG. 2—RATIO OF SURFACE TEMPERATURE RISE AT SEA-LEVEL TO THAT AT A GIVEN ALTITUDE. "m" HAS A DIFFERENT VALUE FOR EACH CURVE

$$\frac{\theta_{s1}}{\theta_{s2}} = \left(\frac{B_2}{B_1}\right)^m$$

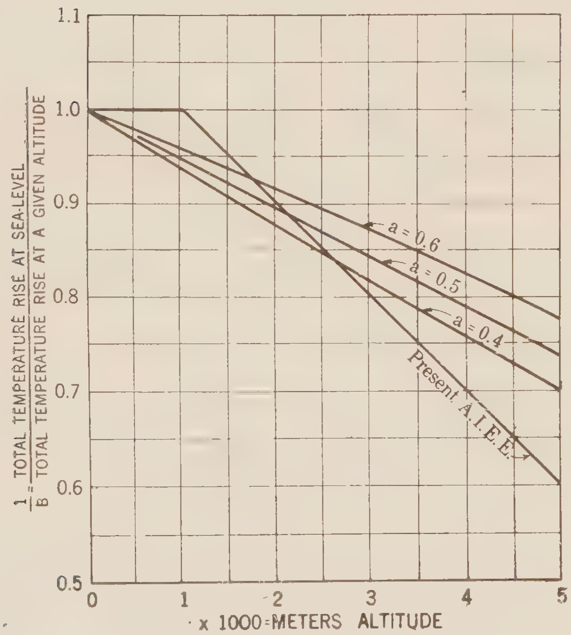

FIG. 3—RATIO OF INTERNAL TEMPERATURE RISE AT SEA-LEVEL TO THAT AT A GIVEN ALTITUDE. "a," THE RATIO OF DROP FROM COPPER TO IRON TO TOTAL TEMPERATURE RISE, HAS A DIFFERENT VALUE FOR EACH CURVE

$$\frac{1}{b} = \frac{\theta_1}{\theta_2} = \frac{1}{a + (1 - a)\left(\frac{B_1}{B_2}\right)^m}$$

m = 0.9 FOR ALL CURVES

values of m. The corresponding ratio, using the provisional A. I. E. E. rules, is also plotted. If the assumption is made that the probable most usual value of m is say 0.9, data from the curve corresponding to that value could conveniently be incorporated in the rules. Or, for m = 0.9, the data may be quite accurately represented by the equation

$$\frac{\theta_{s1}}{\theta_{s2}} = 1 - 0.09 \times \frac{\text{alt.}}{1000} \text{ up to about 4000 meters.}$$

In those machines in which temperatures are measured by embedded temperature detectors, equation (2) may be used. The plots for a = 0.4, 0.5, and 0.6 are given in Fig. 3 for m = 0.9. Those three

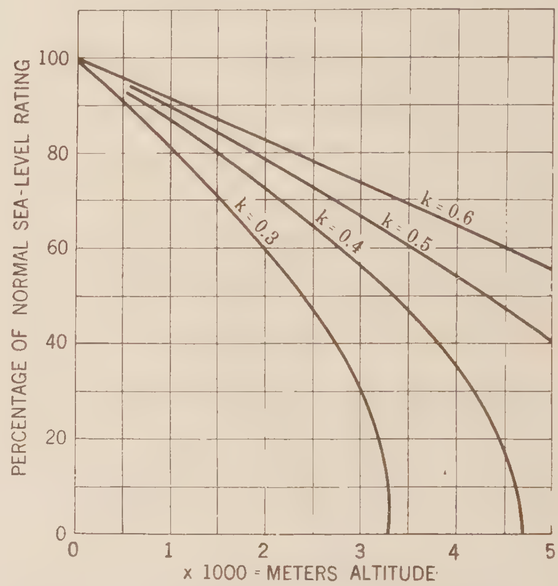

FIG. 4—RATINGS AS AFFECTED BY ALTITUDE. m = .9 FOR ALL CURVES, SURFACE TEMPERATURE ONLY CONSIDERED k, THE FRACTION OF LOSS IN THE CORE THAT IS PROPORTIONAL TO THE SQUARE OF THE LOAD AT SEA-LEVEL, HAS A DIFFERENT VALUE FOR EACH CURVE

$$K = \sqrt{1 - \frac{1}{K}\left[1 - \left(\frac{B_2}{B_1}\right)^m\right]}$$

curves are so nearly straight lines, that their approximate equations may be written as follows:

$$a = 0.4, \frac{1}{b} = 1 - 0.0604\left(\frac{\text{Alt.}}{1000}\right)$$

$$a = 0.5, \frac{1}{b} = 1 - 0.0526\left(\frac{\text{Alt.}}{1000}\right)$$

$$a = 0.6, \frac{1}{b} = 1 - 0.044\left(\frac{\text{Alt.}}{1000}\right)$$

Alt. = Altitude in meters.

The error for the high altitudes is not negligible, when the present A. I. E. E. rule is used. Thus, for a = 0.5, the temperature rise at sea-level is 0.6, instead of 0.785, of the rise at 5000 meters.

It will be noted that equations (1) and (2) do not contain k, the fraction of the loss in the core that is proportional to the square of the load. This follows

because the temperature of the external surface of, say an armature, is independent of the distribution of losses in the copper and iron. This is fortunate, as one less variable means simplification.

When the equations are solved for the rating ratio K, the term k is present. When so solved, the simplest solution, equation (**3**), applies when surface temperatures only are considered, and when the permissible temperature rise at a given altitude is the same at

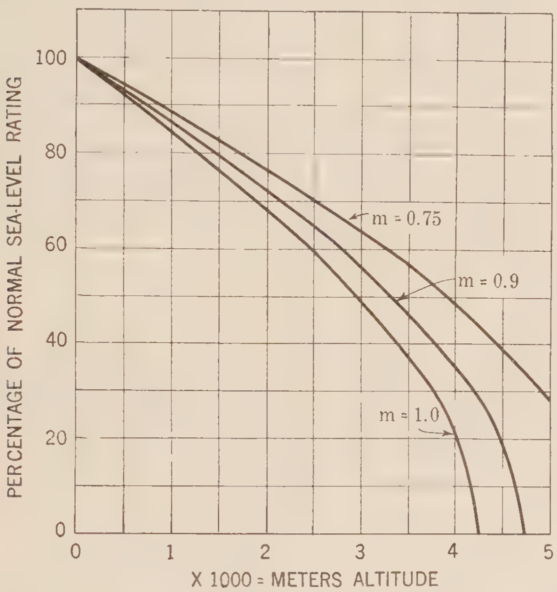

Fig. 5—Ratings as Affected by Altitudes. Surface Temperature only Considered. "m" has a Different Value for Each Curve. k = .4 for All Curves.

$$K = \sqrt{1 - \frac{1}{K}\left[1 - \left(\frac{B_2}{B_1}\right)^m\right]}$$

sea-level. Perhaps that is the form of "rating" equation that an engineer would use most frequently. The percentage of normal sea-level rating may then be read directly from a family of curves, such as are shown in Fig. 4. Those curves were calculated on the basis that the barometric pressure ratio = 0.9, and that the value of k, the fraction of total loss that, at sea-level, is proportional to the square of the load, is constant along any one curve. The value to assign to k is considered in Appendix II. If a fixed value is chosen for k, the equation may again be plotted in the form of a family of curves, the exponent m being fixed for each curve. The value of 0.4 has been chosen for k in the plot in Fig. 5. From data on various machines, it seems as though 0.4 is a fair average value. As stated elsewhere in this paper, a value of 0.9 for m is probably the one that may generally be adopted. It is, therefore, suggested that for machines on which surface temperatures only are measured, the data from either Fig. 4 or 5, for m = 0.9 or k = 0.4 be used.

If again, surface temperatures only are considered, and values be assured for m and k, a family of curves may be plotted with the use of equation (**4**). As shown in Fig. 6, m = 0.9 and k = 0.4. Equations (**3**) and (**4**) are the same except that in (**3**) the temperature rise is taken to be the same at altitude as at sea-level, for a given rating $\left(b = \frac{\theta_2}{\theta_1} = 1\right)$. The ratio b is constant along any curve in the family in Fig. 6. It will be seen that it is quite within the range of possibilities for a machine to be good for a higher rating at a higher altitude than at sea-level. For example, if the air temperature is 40 deg. at sea-level; and the rise is 40 deg., then at a certain location at 3000 meters altitude, where the air temperature is 20 deg., the permissible rise is 40 + 40 − 20 = 60 deg. to secure the same total temperature. The rating may then be, from Fig. 6, 110.5 per cent of sea-level rating.

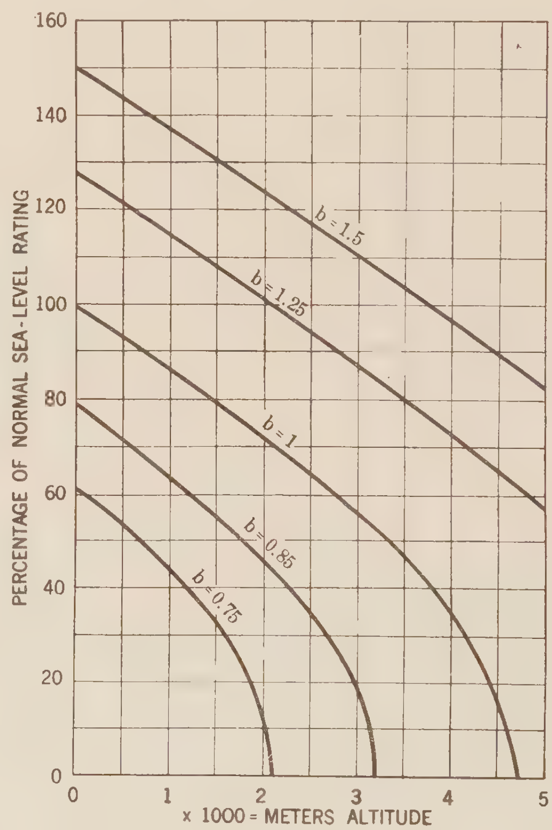

Fig. 6—Ratings as Affected by Altitude. Surface Temperature only Considered m = 0.9 and K = 0.4 for All Curves. B, the Ratio of the Temperature Rise at Altitude to that at Sea-Level, has a Different Value for Each Curve.

Equations (**5**) and (**6**) are solved for the percentage of sea-level rating, account being taken of the drop through the insulation. Thus, the factor a is the ratio of the thermal drop from the copper to the iron to the total temperature rise, at sea-level. The assumption is made that the heat that flows transversely through the insulating wall is the same percentage of the heat generated in the copper at altitude as at sea-level. Evidently these two equations apply only when the temperatures are measured by embedded

temperature detectors. Equation (**5**) is the same as (**6**), except that in (**5**) the temperature rise at altitude is taken to be the same as at sea-level.

With the number of factors, as given in equations (**5**) and (**6**), it becomes more difficult to plot them in families of curves, and such curves are, therefore, not included in this paper. As those equations will probably be of value chiefly to the designer, and as it is necessary to evaluate such factors as k and a, with which frequently only the designer is familiar, he can readily substitute the numerical values in the equations and solve for K.

Appendix I

Derivation of Equations

For the usual case, the slotted core construction is of greatest interest. While that construction is the one chiefly considered, the equations are applicable to other parts. Some cases are considered in Appendix IV.

The derived equations take into account the relative values of $I^2 R$ loss, the percentage thermal drop through the insulating wall, and the comparative allowable temperature rises at altitudes and at sea-level. The equations are simplified if any of these are neglected. Furthermore, the equations can be readily applied if tests have been made at the factory where such items as the barometric pressure, ingoing air temperature, the temperature rise of the iron surface, and of the embedded copper have been measured, or whose approximate values may be assumed. The assumption is made that all heat is dissipated by forced convection currents of air, natural convention and radiation being of negligible influence. The equations, therefore, are not applicable to transformers, totally enclosed machinery, or other apparatus in which those two effects are predominant. The assumption is also made that in a slotted core the heat that flows transversely through the insulating wall is the same percentage of the heat generated in the copper at altitude as at sea-level.

Call L_1 the losses upon which the temperature in the member under consideration are dependent when operating at sea-level. (Usually embedded copper losses plus iron loss). Also k = fraction of loss L_1 that is proportional to square of the load, at sea-level. Then:

$$L_1 = k\,L_1 + (1 - k)\,L_1 \qquad (7)$$

Thus, $k\,L_1$ = variable losses that are proportional to the square of the load, and the remainder, $(1 - k)\,L_1$ = constant losses. At a given altitude, the constant losses are still $(1 - k)\,L_1$, and the variable losses are as at sea-level multiplied by the square of the ratio of ratings. If L_2 is the loss at altitude,

$$L_2 = k\,K^2\,L_1 + (1 - k)\,L_1 \qquad (8)$$

The difference between the surface temperature and that of the cooling medium adjacent to the surface is proportional to the losses, and inversely proportional to a fractional power of the density of the medium. The fractional exponent is probably between 0.75 and 1, and its value is further discussed in Appendix III. The cooling medium, air, is itself heated by the absorption of losses up to the particular surface, and that air temperature rise must be added to the thermal drop from the surface to the adjacent air. The air rise is inversely proportional to the density of the cooling medium. The temperature rise of the surface above the air entering the machine is then made up of two parts, one of which is inversely proportional to the first power of the density ratio and the other is inversely proportional to a power of that ratio whose value is between 0.75 and 1. In the general case, in which the temperature rise above the ingoing air is considered, the resultant exponent is probably not far from 0.9, but in these equations it is written as m. The equation coordinating losses and barometric pressures with surface temperature rise may then be written as:

$$\frac{\theta_{s2}}{\theta_{s1}} = \frac{L_2}{L_1}\left(\frac{B_1}{B_2}\right)^m \qquad (9)$$

Here θ_{s1} = temperature rise of cooling surface above the ingoing air, at sea-level. θ_{s2} = same as θ_{s1}, but at altitude. B_1 and B_2 are respectively the barometric pressure readings at sea-level and at altitude.

From equations (**7**), (**8**) and (**9**),

$$\frac{\theta_{s2}}{\theta_{s1}}\left(\frac{B_2}{B_1}\right)^m = \frac{L_2}{L_1} = k\,K^2 + (1 - k) \qquad (10)$$

Whence, for $\theta_{s2} = \theta_{s1}$,

$$K = \sqrt{1 - \frac{1}{k}\left[1 - \left(\frac{B_2}{B_1}\right)^m\right]} \qquad (11)$$

Equations (**11**) and (**3**), in the text are identical. Assuming that the load at sea-level and at altitude are the same, $K = 1$, and the equation may be written:

$$\frac{\theta_{s1}}{\theta_{s2}} = \left(\frac{B_2}{B_1}\right)^m \qquad (12)$$

This is the same as equation (**1**) in the text.

Consider next the transverse flow of heat through the insulation wall adjacent to the copper in the slot, the total temperature rise of the copper above the ingoing air θ_2 is the sum of the drop through the insulating wall θ_{i2} and the surface rise θ_{s2}. That is:

$$\theta_2 = \theta_{s2} + \theta_{i2} \qquad (13)$$

Similarly at sea-level, using subscripts 1 instead of 2,

$$\theta_1 = \theta_{s1} + \theta_{i1} \qquad (14)$$

The heat flows in part transversely through the insulation from the copper to the iron, and in part longitudinally and the relations are too complex to embody in these equations.[3] (In some cases the flow may be from the iron to the copper). It is believed, however, to be reasonable to assume that the percentage of the total heat generated in the copper that flows trans-

3. Those equations will be found in a paper by the author: "Longitudinal and Transverse Heat Flow in Slot Wound Armature Coils." Trans. A. I. E. E., 1921, p. 589.

versely is the same at a given altitude as at sea-level. The difference in temperature between the copper and the cooling surface may then be taken as proportional to the copper losses:

$$\frac{\theta_{i2}}{\theta_{i1}} = \frac{K^2 k L_1}{k L_1} = K^2 \tag{15}$$

Call a the ratio of the drop from the copper to the cooling surface to the total temperature rise at sea-level:

$$a = \frac{\theta_{i1}}{\theta_1} \tag{16}$$

One other factor may enter, as the permissible temperature rise at a given altitude is frequently greater than at sea-level, due to the lower ambient temperature at the higher altitudes. The ratio of the permissible rise is:

$$b = \frac{\theta_2}{\theta_1} \tag{17}$$

Equations (**10**), (**13**), (**14**), (**15**) and (**16**) may readily be combined, and the solution may be written as:

$$K = \sqrt{\frac{b - (1-k)(1-a)\left(\frac{B_1}{B_2}\right)^m}{a + k(1-a)\left(\frac{B_1}{B_2}\right)^m}} \tag{18}$$

This is the same as equation (**6**) in the text. By taking the ambient temperature at sea-level to be the same as at altitude, $b = 1$, equation (**5**) is obtained. If in (**18**), a, the ratio of the drop from the copper to the iron to the total temperature rise at sea-level, be taken as zero, equation (**4**) is obtained. Then, again, if in equation (**4**), $b = 1$, equation (**3**) follows. Also, if in equation (**18**) the ratio of ratings at altitude and at sea-level be taken as unity, equation (**2**) is obtained. Equation (**1**) may be obtained from (**2**) by placing $a = 0$. Then the surface rises (θ_{s1} and θ_{s2}) are taken to be equal to the total rises θ_1 and θ_2.

Appendix II

Discussion of Values of k

The value of the fraction of the embedded loss that is proportional to the square of the load k is necessarily largely dependent upon the type of machine, upon the speed, upon the voltage, upon the choice of proportions by the designer, etc. A number of machines of three types were chosen at random, as given in the table.

SALIENT POLE ALTERNATORS
Rating at Sea Level

Kv-a.	Volts	Frequency	Rev. per min.	k
18750	12000	60	150	0.498
1250	13200	60	112	0.302
850	2200	60	100	0.730
12500	13200	60	720	0.370
10000	15000	50	600	0.590
				0.498 = Av. k

LARGE INDUCTION MOTORS

H. p.	Volts	Frequency	Syn. Rev. per min.	k
1200	2200	60	600	0.206
1200	6600	25	500	0.475
1400	2200	60	514	0.448
1500	6600	25	375	0.320
1200	2200	60	300	0.316
1500	2200	60	360	0.357
				0.353 = Av. k

D-C. GENERATORS AND MOTORS

Kw.	Volts	Rev. per min.	k
500	250	1200	0.216
1000	250	720	0.380
1500	250	514	0.420
300	250	150	0.407
600	250	100	0.450
1000	250	100	0.508
			0.397 = Av. k

Mean of the three values of k = .416

From Fig. 4 it will be seen that the value of k has considerable influence upon the rating. For the general average case, the value of 0.4 is probably not far wrong. The curves in Figs. 5 and 6 were plotted for that value. Inasmuch as the equations involving k are of principal value to the designer, he can readily determine the proper value to assign to it, and estimate the rating at the higher altitude by substituting in the proper equation. For short machines the longitudinal flow affects the distribution, and for such machines the value of k should be reduced.

Appendix III

Discussion of Values of m

The value to assign to m, the barometric pressure ratio exponent, could easily be made the subject of an entire paper. Only a brief outline of the subject and mention of several papers are given in this note. As stated in Appendix I, m is dependent upon two factors which are additive, (a) the rate at which heat is transferred from a heated surface to the moving fluid, and (b) the temperature increase of the cooling fluid from entrance to the machine up to the point under consideration. These two do not bear a fixed relation to each other; in one type of machine the relation may be quite different from another type. For example, in a d-c. armature, the temperature rise of the air up to the parts of the radial vents considered is probably quite small; on the other hand, in a high speed steam-turbine driven alternator the air rise is usually considerable before it reaches those parts of the vent ducts which are closest to the points where the temperatures are measured.

The volume of air per unit time which passes through a machine is independent of the barometric pressure. (This follows because the pressure generated by the fans, and the pressure drop through the various paths of the machine are both proportional to the density, and the generated and consumed pressures are equal to

each other). As the mass of air per unit of time is proportional to the density, the mass varies directly with the density or with the barometric pressure. As the temperature rise of the air is inversely as its mass, (assuming that the same heat is taken up by the air), the temperature rise is inversely as the barometric pressure.

In regard to the rate of transfer of heat from the surface to the cooling medium, there are a number of papers available. Perhaps the best work is that of Nusselt[4], and he found experimentally that the density ratio exponent is 0.786. Pohl[5] used that value in the derivation of equations applicable to machines using a closed circuit system of cooling. One of the most recent publications is that of Rice[6], who obtains his results largely theoretically, using the dimensional method, and in his final equations for heat transfer for the turbulent state of ideal gases, for smooth and for moderately rough surfaces, the exponent of density is given as unity. Rice's paper contains a large number of references, and any one interested can consult that paper. In the paper by Doherty and Carter[7], the exponent for forced convection was found to be 0.73, and to simplify calculations, they used 0.75. This value seems to be approximately correct for the machines for which they give data in their paper. As we understand their results, the exponent 0.75 takes account of the air rise as well as the surface transfer. It is felt, however, that their tests are too limited to warrant us to draw conclusions.

It is believed that, since the total drop is made up of two items which are additive, and since the exponent for one of them is probably not far from 0.80, and the other is unity, a mean of 0.9 may be chosen for the general case. It would be well to obtain further experimental checks. As may be seen from Figs. 2 and 5, if 0.9 be adopted, the error in temperature or in rating is not great for probable departures above or below this value.

Appendix IV

Cases Other Than A Slotted Core

The manner of treatment of a few cases other than a slotted core will be considered.

1. Commutators.

The losses are evidently the brush friction and $I^2 R$, the influence of windage loss upon temperature being negligible. The friction losses are evidently constant and the $I^2 R$ losses are proportional to the square of the load. Equations (**1**), (**3**) and (**4**) are applicable.

4. Nusselt. "Heat Transmission in Conduits," *Zsch. d. V. D. I.*, 1909, p. 1808.

5. Robert Pohl. "Fundamentals of Heating Calculations of Electric Machines, Especially Turbo Generators, Cooled by the Circular Process." *Arch. f. Elek.*, 1923, p. 361.

6. C. W. Rice. "Forced Convection of Heat in Gases and Liquids." *Industrial and Engineering Chemistry*, May, 1924, p. 460.

7. "Effect of Altitude on Temperature Rise." Trans. A. I. E. E., 1924, p. 824.

2. Stationary Field Coils as in D. C. Machines.

A. Shunt Coils. If the field current may be assumed to be the same at all loads, and surface temperatures are to be measured, equations (**1**), (**3**) or (**4**) may be used; otherwise, if the temperature rise is measured by resistance, equations (**2**) (**5**) or (**6**) may be used, taking $k = 1$. If the field current changes with the load, the temperature equations (**1**) or (**2**) may still be used. Unless the change in current with load can be incorporated in a simple equation which can be combined with other elementary equations, the rating may be approximated by a cut-and-try method.

B. Series or interpole coils, or compensating windings. The current is proportional to the load, and the losses to the square of the load. If the surface temperatures only are to be measured, equations (**1**), (**3**) or (**4**) may be used, taking $k = 1$. If these windings are insulated and temperatures are measured by resistance, equations (**2**), (**5**) and (**6**) may be employed.

It is recognized that, due to change in armature losses with load, the temperature of the cooling air changes with the load. That introduces a complication, and furthermore, its influence is usually small, if consideration is given to the fact that at the higher altitude the rating and losses are reduced.

3. Revolving Field Alternator Field Coils.

A. Single layer edgewise winding. Temperatures measured by resistance. The temperature rise for a given load may be estimated by equation (**1**). The changed rating may be estimated by approximating the field current for various loads, and with the use of equation (**1**), calculate the temperature rise ratio. A curve may then be plotted coordinating temperatures with ratings.

B. Embedded windings, such as for turbo alternator rotors; or field coils for salient pole alternators with insulation. Temperature rise measured by resistance. Equation (**2**) may be used for temperature rise ratio. The changed rating may be estimated in the same manner as for single layer edgewise winding, except that equation (**2**) should be used instead of equation (**1**).

RAILWAY ELECTRIFICATION IN JAVA PLANNED

According to recent reports the electrification of the line Manggarai-Buitenzorg has been sanctioned by the Government. Plans for the project are now entirely completed, the execution of the work has already been commenced, and the necessary material will be ordered immediately. Barring unforeseen circumstances, it is expected, therefore, that the electrification of the entire line will be completed in two years. Furthermore, an amount of 100,000 guilders (the guilder now = $0.40) has been appropriated for preliminary work in connection with the electrification of the Poerwakarta-Bandoeng line, which will probably be the next to be electrified.

A New Wave-Shape Factor and Meter

BY L. A. DOGGETT, J. W. HEIM and M. W. WHITE*
Member, A. I. E. E. Non-Members

***Synopsis.**—A star-connected circuit consisting of two voltmeters and one variable condenser has certain properties upon which a wave-shape factor may be based. When the voltmeter resistances are equal to each other and equal to the condenser reactance, the ratio of the voltmeter readings will always be $(2 + \sqrt{3})$ for an alternator producing sine waves and always less than $(2 + \sqrt{3})$ for all other wave shapes. From any measured ratio of voltmeter readings, the purity of the voltage wave may be determined; furthermore, the maximum possible percentage of any single harmonic present in the wave can be immediately obtained (See Table III). For the experimental application of this method a wave shape meter is proposed for practical application which consists essentially of two voltmeters and a variable condenser. Such a meter has advantages over the method of analysis based on oscillograms, namely: (1) cost, (2) portability, (3) ease of experimental procedure and (4) rapidity of arriving at results. This method of attack is not intended to supplant the oscillograph but rather to supplement it. The method has been checked with the aid of a harmonic alternator and has been applied to the local power system and to various alternators available in the Electrical Engineering laboratories of the Pennsylvania State College.*

* * * * *

Introduction

FOR a long time the wave shape standard of the A. I. E. E. has been based on oscillograms. Recently† copies of seven oscillograms were sent to ten electrical manufacturing and power companies for measurement of deviation factor. The results obtained showed very considerable variations. For one oscillogram, the values found for this factor ran from 1 to 4.2 per cent, with an average value of 2.25 per cent. In other words, the maximum value was in excess of the average by 86½ per cent of the average value, while the spread between the maximum and minimum values was 3.2 or 142 per cent of the average value. For the other six curves the spread was less, but still considerable. The excess of the maximum values over the average values for each of the six other cases was 57 per cent, 54 per cent, 52 per cent, 47 per cent, 31 per cent, and 14 per cent. Quoting from the reference given, "The variations between results cannot be attributed to the processes of calculation employed, for neither the maximum nor the minimum spread occurred with the same party. The variations must, therefore, arise from difficulties inherent in the method such as, difficulty in evaluating exactly the ordinates of the oscillogram, errors in evaluating the area included by the squares of the ordinates in finding the effective value, errors in measuring the maximum differences between the ordinates of the oscillogram and the equivalent sine wave, especially when these differences occur in the steep part of the curve."

Another test was made to determine the accuracy attainable in the determination of the amplitudes of harmonics by analysis of oscillograms. Three waves were prepared by the synthesis of known harmonics and fundamental, the waves traced, and the results turned over to various parties to be analyzed. The results indicated that for harmonics below the 15th, average variations from the correct values of amplitudes of harmonics of ± 5 per cent might be expected.

The usual alternative to the use of the oscillograph is some sort of a circuit method of which many have been proposed but so far no one has been permanently adopted. Here still another circuit method is proposed, differing primarily from other circuit methods in that it is based on a three-phase circuit.

Description of the Method

Two voltmeters, V_2 and V_3 (Fig. 1) having equal resistances, and a variable condenser, C (whose range of reactance can be varied above and below the resistance of the voltmeters) are connected in star to the three-phase source whose wave shape is to be investigated. The value of C is adjusted until the ratio of the larger to the smaller voltmeter readings is maximum. That this ratio, R, is $(2 + \sqrt{3})$ for a pure sine wave is proved in the Appendix. The greater the deviation from a pure sine wave, the lower this ratio will become. It is the dependence of this ratio upon the harmonics present in the wave which makes it possible to use such a voltage ratio as a measure of the purity of the wave.

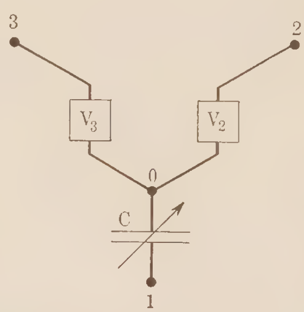

Fig. 1 a—A New Wave-Shape Factor

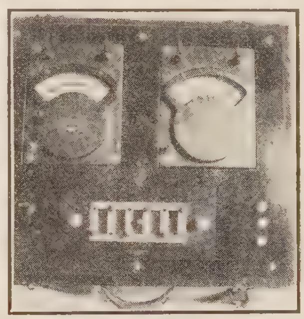

Fig. 1 b—Wave-Shape Factor and Meter

The vector diagram of Fig. 2 gives an idea of the displacement of the neutral as the wave shape departs from a true sine wave.

By the use of the following formula, also proved in the

*All of Pennsylvania State College, State College, Pa.

†*Revue Generale de L'Electricite*, January 10, 1925, pp. 43-46.

To be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926.

Appendix, the voltage ratio for any combination of harmonics may be calculated,

$$R = (2 + \sqrt{3}) \left[\frac{100 + a_2\,(\%\,H_2)^2 + a_3(\%\,H_3)^2 + \ldots\, a_n(\%\,H_n)^2}{100 + b_2\,(\%\,H_2)^2 + b_3(\%\,H_3)^2 + \ldots\, b_n(\%\,H_n)^2} \right]^{1/2} \qquad (1)$$

Where $\%\,H_2$ is the per cent second harmonic.
$\%\,H_3$ " " " " third "
$\%\,H_n$ " " " " n^{th} "

The a and b constants for the various harmonics are given in Table I.

TABLE I

Harmonic	a	b
2	0.0026	0.1967
4	0.0160	0.0939
5	0.0080	0.2230
7	0.0157	0.1330
8	0.0101	0.2165
10	0.0153	0.1500
11	0.0110	0.2106
13	0.0149	0.1590
14	0.0115	0.2066
16	0.0147	0.1640
17	0.0119	0.2036
19	0.0145	0.1680
20	0.0122	0.2014
22	0.0144	0.1710
23	0.0124	0.1993
25	0.0142	0.1730
∞	0.0134	0.1866

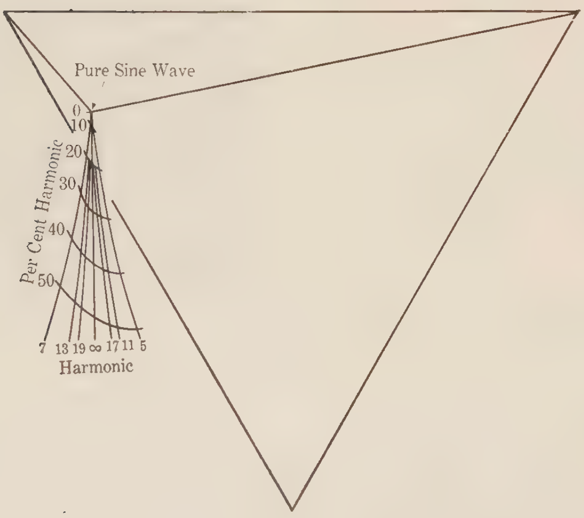

FIG. 2—LOCI OF FLOATING NEUTRAL FOR VARIOUS PERCENTAGES OF HARMONICS. (LINE VOLTAGE CONSTANT)

Since in the experimental application of this method, two voltmeters having equal resistances are required and as one meter must have a range approximately three times that of the other, some difficulty was experienced in selecting suitable meters from standard models, those of the dynamometer type being desired.

The meters first selected were a Weston instrument with a resistance of 301 ohms and a range of 30 volts, and a General Electric instrument having a resistance of 920 ohms and a range of 150 volts. Each voltmeter was equipped with a multiplier so as to arrange the resistance of V_2 in Fig. 1 equal to that of V_3. The voltmeters were then calibrated. Three one-μf mica and one eight-μf paper condenser were used. The capacities of these condensers were also checked.

The final arrangement, as shown in the photograph, Fig. 1, consists of two Weston dynamometer type voltmeters of 40- and 120-volts range respectively and of 1000.7- and 1000.0- ohms resistance respectively.

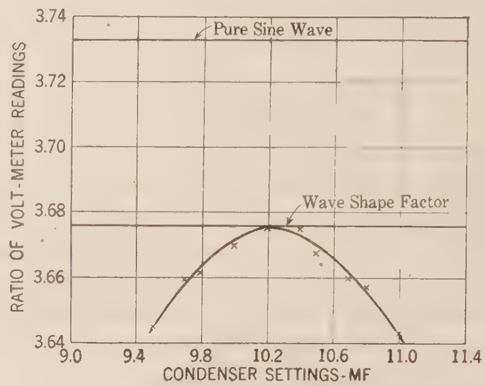

FIG. 3

Mounted in the same box are a one-μf. mica and two one-μf. paper condensers. The mica condenser is a Leeds and Northrup instrument, variable by steps of one twentieth μf. from 0 to one μf. The small

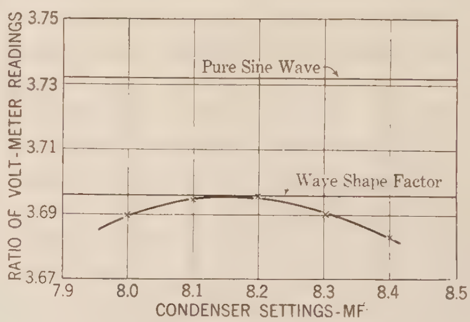

FIG. 4

switch in the lower left hand corner controls the paper condensers, giving zero, one, or two μf.

SOME APPLICATIONS OF THE METHOD

With the apparatus as originally set up, tests were made on waves obtained from the Keystone Power Corporation System, from the Pennsylvania State College Power Plant (300 kv-a. turbo alternators), and various laboratory alternators. In the curves of Figs. 3 and 4 are plotted the data for two representative cases.

To obtain data for the curves of Fig. 5 the final arrangement shown in the photograph of Fig. 1 was used. If the following technique is employed, and if the frequency remains constant for about five minutes,

the results obtained are independent of voltage, capacity and magnitude of line frequency. The technique employed in obtaining the five dotted curves of Fig. 5 was to vary rapidly the capacity from 2.0 to

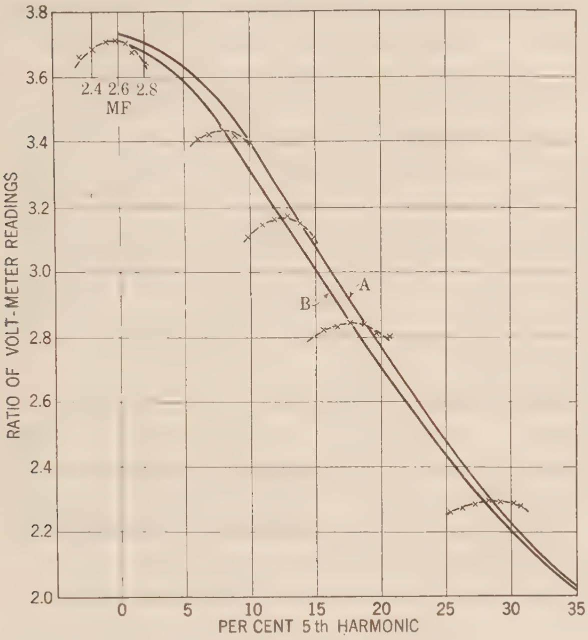

Fig. 5

3.0 $\mu f.$ by 0.1 $\mu f.$ steps, reading the two voltmeters at each step. The maximum ordinate of the plot of the ratio of these observations is the wave-shape factor.

Check of Observations Against Calculations

In order to check this method the following test was carried out. The fundamental and fifth harmonic members of a three-phase harmonic alternator were used. A description of this machine is given in the Appendix. The phases of the fundamental machine were star connected, and each phase joined in series with the proper coil of the fifth-harmonic machine. This three-phase supply was connected to the wave shape meter (Fig. 1). Ratio curves, such as shown in Fig. 5 were obtained for 0 per cent, 8.0 per cent, 12.8 per cent, 17.5 per cent, and 28.0 per cent fifth harmonics. Through the maximums of the five dotted curves is drawn a curve, B, which should check with curve A, the latter being calculated from formula (**1**). Discrepancies between curves A and B are chargeable to deviation from a pure sine wave on the part of the fundamental machine and to slight inequalities in the magnitudes of the three-phase voltages of the fifth harmonic machine. In searching for various factors to account for this discrepancy it was proved by test that the wave-shape factor is independent of the phase position of the harmonics.

Conclusions

1. *Value of Voltage Ratio to Be Met in Practise.* In addition to the values of wave shape factors given above for systems and dynamos tested in our laboratories, there is given in Table II, a compilation of wave-shape factors for some waves whose analyses into component harmonics have been found in the literature. It will be seen that wave-shape factors varying from 3.448 to 3.730 appear in practise. These factors were obtained by substituting the given percentage harmonics in formula (**1**).

TABLE II

Wave-Shape Factor	Per cent Harmonic									Reference
	3	5	7	9	11	13	15	17	19	
3.712	0	2	1.44							1
3.605	0	5.3	2.46	0	1.04	1.2				2
3.715	0	1.77	1.22	0	0.48	0	0	0.395	0.294	2
3.633	13¼	5	1.2	0.9						2
3.676	0	3.5	1.6							3
3.493	3.67	8.05	1.63	0.058						4
3.520	0.98	7.6								4
3.448	7	9								5
3.670	3	4								5
3.730	0.46	0.724								6
3.724	5.5	1.25	0.49	0.55	0.37					6
3.591	2.92	5.2	0.66	1.07	0.62	3.77	4.6	0.48		6
3.555	2.83	5.43	5.51	0.26	1.28	0.51	0.23	0.09		6
3.624	1.0	2.73	2.2	0.41	4.4	0.79	0.23	0.09		6

1. "Specification and Design of Dynamo-Electric Machinery," Miles Walker, p. 332.
2. Trans. A. I. E. E., Vol. 32, 1913, p. 781.
3. Trans. A. I. E. E.., Vol. 38, 1919, p. 1185.
4. Trans. A. I. E. E., Vol. 23, 1904, p. 408.
5. *Electrician*, Aug. 6, 1909.
6. Bureau of Standards, Vol. 9, 1913, p. 567.

Oscillograms were obtained from 19 machines of Table I of the 1919 report of the A. I. E. E. Subcommittee on Wave Shape Standards[13]. Based on analyses of these waves, the following wave shape factors were calculated:

3.717, 3.706, 3.717, 3.719, 3.698, 3.723, 3.715, 3.724, 2.746, 3.700, 3.700, 3.696, 3.698, 3.702, 3.700, 3.708, 3.702, 3.553, 3.349; *i. e.*, a range of 3.724 to 2.746.

2. *Interpretation of Voltage Ratios.* As previously stated a ratio of voltmeter readings of $(2 + \sqrt{3})$ or

13. Osborne

3.732 corresponds to a pure sine wave. Consequently the purity of a voltage wave may be immediately determined by noting whether or not the observed voltage ratio is equal to 3.732.

In case the ratio is found to be less than $(2 + \sqrt{3})$ it follows that the wave is not a pure sine wave. We may assume the absence of third harmonics or any multiple thereof in the ordinary commercial three-phase circuits. Furthermore, no second or fourth harmonics will be found in the waves from commercial alternators.

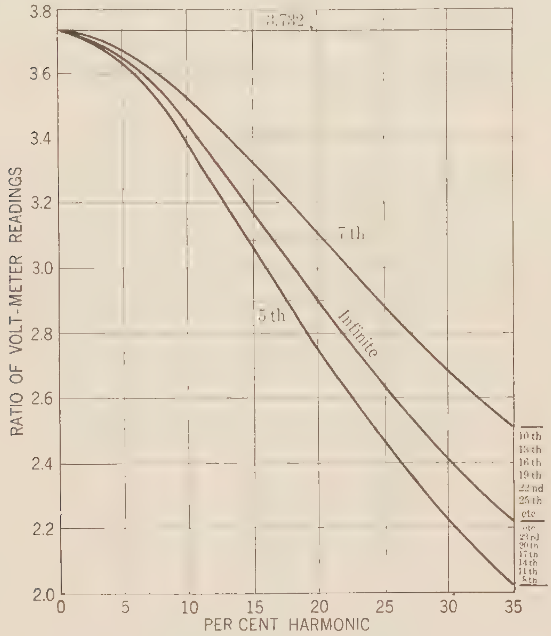

Fig. 6

The fifth and seventh harmonics are usually the most pronounced of all the harmonics, and Fig. 6 shows the ratio curves for these harmonics. If only a seventh harmonic is present, reference to Table III will immediately give the percentage harmonic corresponding to any observed voltage ratio.

TABLE III

7th Harmonic

Per cent Harmonic	Voltage Ratio
0	3.7320
1	3.7298
2	3.7232
3	3.7123
4	3.6974
5	3.6753
6	3.6530
7	3.6248
8	3.5999
9	3.5685
10	3.5298
11	3.4962
12	3.4572
13	3.4163
14	3.3742
15	3.3312

Reference to the curves of Fig. 6 shows that a given voltage ratio corresponds to a smaller percentage harmonic when this is a harmonic of an order other than the seventh. Consequently the *maximum* possible percentage of any single harmonic present may be immediately obtained from the observed voltage ratio by reference to Table III. For example, a voltage ratio of 3.33 corresponds to the presence of a 15 per cent seventh harmonic (From Table III) and inasmuch as this ratio corresponds to a smaller percentage of any single harmonic other than the seventh, it is quite conservative to state that in a circuit which gives an observed voltage ratio of 3.33, there is no single harmonic present which amounts to more than 15 per cent of the fundamental. In other words, this last deduction holds not only for the case where the seventh alone is present but also where there are other harmonics found in addition to the seventh.

In brief, it can be stated that this method is capable of giving at once from a single observation of voltage ratio, the maximum possible percentage of any harmonic present in a wave, when the experimental conditions have been properly adjusted as described above.

3. *Accuracy of Results.* The accuracy with which the data may be obtained is quite high. The method is independent of voltage, since only the ratio of the two phase voltages is required and this ratio is independent of the actual voltage used. The frequency need not be measured, provided means of checking its constancy are available; this can be conveniently done by any frequency meter. If good mica condensers are used the accuracy with which they are guaranteed by the manufacturers (say ¼ per cent) is more than sufficient for our purpose, since the actual value of the capacitance does not enter directly into the computations. Consequently, the main factor which limits the precision of the measurements is the accuracy of the calibration of the voltmeters and our ability to read the same. The probable error of the voltage ratio, including instrumental and observational errors, will not exceed 0.2 per cent.

Our experiments have indicated that the use of the iron-vane type of voltmeter is not very satisfactory for this purpose.

Appendix I

Proof that $\dfrac{V_2}{V_3} = R = 2 + \sqrt{3}.$ for a pure sine wave: The following formula has been derived in a previous paper* for calculating the voltage to neutral for any branch of the star-connected circuit of Fig. 1.

$$I_p Z_p = E\left[a^{p-1} - \frac{a^0/Z_1 + a^1/Z_2 + \; . \; . \; . \; . \; a^{n-1}/Z_n}{1/Z_1 + 1/Z_2 + \; . \; . \; . \; . \; 1/Z_n}\right] \tag{a}$$

*Doggett. "Floating Neutral n-Phase Systems" Trans. A. I. E. E., Vol. 42, 1923, p. 800.

where,
E is the numerical value of the impressed voltage to geometrical neutral.

$a = \cos 2\pi/\phi + j \sin 2\pi/\phi$ for counter clockwise rotation.
$a = \cos 2\pi/\phi - j \sin 2\pi/\phi$ for clockwise rotation.
ϕ = number of branches or phases.
Z_1 = impedance between 0 and 1 (see Fig. 1)
Z_2 = impedance between 0 and 2 (Fig. 1).
Z_n = impedance between 0 and n (Fig. 1).
p = 1, 2 or 3 for a three-phase system.

Assuming that the impedance of each meter is 1000 ohms resistance (inductance negligible†) and that of the condenser is also 1000 ohms (capacitive reactance), the reading of the voltmeter V_2 according to equation (**a**) is,

$$I_2 Z_2 = E\left[(-1/2 - j\sqrt{3}/2) - \frac{\dfrac{1}{-j\,1000} + \dfrac{-1/2 - j\sqrt{3}/2}{1000} + \dfrac{-1/2 + j\sqrt{3}/2}{1000}}{\dfrac{1}{-j\,1000} + \dfrac{1}{1000} + \dfrac{1}{1000}}\right]$$

$$= E\left[-1/2 - j\sqrt{3}/2 - \frac{j-1}{j+2}\right]$$

Rationalizing the last term, reducing and collecting,

$$I_2 Z_2 = \frac{E\,[-3 - j\,(6 + 5\sqrt{3})]}{10} = V_2$$

Proceeding in a similar manner, the reading of V_3 is,

$$I_3 Z_3 = \frac{E\,[-3 - j\,(6 - 5\sqrt{3})]}{10} = V_3$$

Then the ratio R,

$$= \frac{V_2}{V_3} = \frac{-3 - j\,(6 + 5\sqrt{3})}{-3 - j\,(6 - 5\sqrt{3})}$$

Combining real and j terms of both numerator and denominator, and rationalizing,

$$R = 2 + \sqrt{3} = 3.732.$$

(Q. E. D.)

Appendix II

Proof of Equation (1). (General formula for calculating R for any number of harmonics of known percentage).

Notation.

E_1' = Fundamental component of voltage across V_2.
E_2' = 2^d harmonic component of voltage across V_2.
E_3' = 3^d harmonic component of voltage across V_2.
E_n' = n^{th} harmonic component of voltage across V_2.
E_1'' = Fundamental component of voltage across V_3.
E_2'' = 2^d harmonic component of voltage across V_3.
E_3'' = 3^d harmonic component of voltage across V_3.
E_n'' = n^{th} harmonic component of voltage across V_3.

Then,

$$R = \left[\frac{(100\,E_1')^2 + (\%\,2^d\,E_2')^2 + (\%\,3^d\,E_3')^2 + \ldots (\%\,n^{th}\,E_n')^2}{(100\,E_1'')^2 + (\%\,2^d\,E_2'')^2 + (\%\,3^{d}\,E_3'')^2 + \ldots (\%\,n^{th}\,E_n'')^2}\right]^{1/2} \quad (\mathbf{b})$$

Constants are worked out for the fundamental and fifth harmonic, in the following sample calculations, Using formula (**a**),

$$E_1' = -0.5 - j\,0.866 - \frac{-1 + j}{2 + j}$$ (Calculated in Appendix I)

Rationalizing the last term and collecting,

$$E_1' = -0.3 + j\,1.466$$

Combining real and j terms and squaring,

$(E_1')^2 = 2.24.$

Similarly,

$$E_1'' = -0.5 + j\,0.866 - \frac{1 + j}{2 + j}$$

$(E_1'')^2 = 0.161.$

Similarly, remembering that the phase rotation of the fifth harmonic is opposite to that of the fundamental*,

$$E_5' = -0.5 + j\,0.866 - \frac{-1 + j\,5}{2 + j\,5}$$

$(E_5')^2 = 1.794.$

$$E_5'' = -0.5 - j\,0.866 - \frac{-1 + j\,5}{2 + j\,5}$$

$$= -1.293 - j\,1.383$$

$(E_5'')^2 = 3.585$

Equation (**b**) can be transformed into equation (**1**) by factoring out the ratio for the fundamental sine wave, $(2 + \sqrt{3}.)$ The b constants are derived from the E'' constants in equation (**b**):

$$b_5 = (E_5'')^2 \times \frac{1}{0.161} = \frac{3.585}{0.161} = 22.3$$

The a constants of equation (**1**) are derived from the E' constants of equation (**b**):

$$a_5 = (E_5')^2 \times \frac{1}{0.161} \times \frac{1}{(2 + \sqrt{3})^2}$$

$$= 1.794 \times \frac{1}{0.161} \times \frac{1}{13.92} = 0.80$$

†The inductance of the meters was found to be too small to affect these calculations appreciably.

*Fortescue, Trans. A. I. E. E., Vol. 37, 1918, p. 1027.

Appendix III

The Harmonic Alternator. The various harmonic voltages were obtained by means of a special harmonic alternator. This machine consists of three three-phase a-c. generators of the revolving field type, one of which is a 15 kw., 60-cycle machine; the second has a capacity of 7½ kw. at 180 cycles, and the third, 3-kw. at 300 cycles. All three machines are mounted on the same bed-plate and have a common frame while the field coils of all machines are mounted on the same shaft. The armature of the 60-cycle machine is stationary, but the armature of the 180-cycle machine may be moved by means of a hand wheel through an angle corresponding to 360-electrical degrees, and the armature of the 300-cycle machine by similar means can be moved through an angle corresponding to 600-electrical degrees. The six terminals of the armature winding of each machine are connected to a switchboard so that the three-phase windings may be connected either in star or delta. The field control of each generator is independent of the other two fields. The machine is driven by a d-c. shunt motor and the field winding is separately excited.

Bibliography

1. Pupin, "Resonance Analysis of Alternating and Polyphase Currents," Trans. A. I. E. E., Vol. 11, 1894, p. 523.

2. Ryan, "Determination of the Wave Form of Alternating Current Without a Contact Maker," Trans. A. I. E. E., Vol. 16, 1899, p. 345.

3. Townsend, "A New Method of Tracing A-C Curves," Trans. A. I. E. E., Vol. 17, 1900, p. 5.

4. Owens, "A New Curve Tracing Instrument," Trans A. I. E. E. Vol. 19, 1902, p. 1123.

5. Ryan, "The Cathode-Ray A-C. Wave Indicator," Trans. A. I. E. E., Vol. 22, 1903, p. 539.

6. Robinson, "The Oscillograph and Its Uses," Trans. A. I. .E. E., Vol. 24, 1905, p. 185.

7. Davis, "A Proposed Wave Shape Standard," Trans. A. I. E. E., Vol. 32, 1913, p. 775.

8. Bedell, "Form Factor and Its Significance," Trans. A. I. E. E., Vol. 34, 1915, p. 1135.

9. Bedell, "Distortion Factors," Trans. A. I. E. E., Vol. 34, 1915, p. 1159.

10. Curtis, "Order and Amplitude of Harmonics in Voltage Wave Forms with Indicating Instruments," Trans. A. I. E. E., Vol. 38, 1919, p. 1179.

11. Dellenbaugh, "An Electromagnetic Device for Rapid Schedule Harmonic Analysis of Complex Waves," Trans. A. I. E. E., Vol. 40, 1921, p. 451.

12. Bedell, "Characteristics of the Admittance Type of Wave Form Standard." Trans. A. I. E. E., Vol. 35, 1916, p. 1155,

13. Osborne, "Review of Work of Subcommittee on Wave Shape Standard of the Standards Committee," Trans. A. I. E. E., Vol. 38, 1919, p. 261.

For a more complete bibliography see references 6 and 11 above.

U. S. HAS FIVE RADIO STATIONS TO EVERY ONE IN EUROPE

In the United States there are more than five times as many radiocasting stations as in all Europe. The total for the United States, according to the most recent statistics, is about 575, while the European total is but 110 radiocasting stations.

England leads European countries; Germany comes next; Spain is third.

By countries, the number of radio stations in Europe is as follows: Finland, eight; Norway, six; Sweden, one; Holland, one; Belgium, four; Irish Free State, two; Great Britain and the North of Ireland, twenty-one; Germany, twenty; France, twelve; Spain, thirteen; Portugal, none; Switzerland, four; Italy, six; Austria, five; Hungary, two; and Czechoslovakia, five.

TERMS OF APPLICATIONS FOR BROADCASTING LICENSE IN INDIA CHANGED

The Government of India has amended the conditions to be complied with by private enterprise in applying for a license to provide a broadcasting service in British India and Burma. It is now provided that at the expiration of the first five years the government will reserve the right to reduce the proportion of license payable to the company so that it will cover the cost of an adequate service, provide a reasonable reserve fund, and pay a dividend of 15 per cent per annum on the subscribed capital. This dividend was originally limited to 10 per cent. It has also been agreed that consideration will be given to applications which provide that importers shall pay a royalty on imported apparatus to the broadcasting company.

VOLTAGE FOR HOME USE

It is apparent that domestic loads have grown so large that serious attention must be given both to voltage regulation in the homes and to wiring in the homes. The houses are becoming miniature machine shops with a variety of motors and heating devices which are bound to cause voltage fluctuations if the wiring does no more than comply with the formal Underwriters' regulations. Some of the appliances, such as the electric refrigerators, automatic pumps, ventilating motors and oil-burner motors, have no respect for time or load and may start up at the peak period or at night when all lights are burning. These voltage fluctuations are annoying because of their effect on the lights, and they may become more so as relays and controls are developed and used for household applications.

The utility may enlarge transformers and secondary distribution copper and yet not improve the situation materially. The answer to the problem lies in the wiring of each home, the motors used on devices and the development of some kind of house voltage regulator.—*Electrical World.*

Current Limiting Reactors
with Fire-Proof Insulation on the Conductor

BY F. H. KIERSTEAD[1]

Associate, A. I. E. E.

Synopsis.—*In a previous paper, tests were described which proved conclusively that if conducting material were lodged between the turns of a reactor having bare conductor, the reactor would flash-over at the instant a failure occurred on the circuit in which the reactor was placed. In this paper, tests are described which were made during the development of a proper insulation for the conductor of reactors.*

Short Circuit Tests. *Reactors tested consisted of one reactor with enameled conductor and two reactors with asbestos insulated conductor; one having a thin covering of asbestos; the other a thicker covering.*

The reactor with enameled conductor flashed over during the first short circuit test. That with a thin covering of asbestos stood one short circuit and arced over in the second short circuit. The reactor with the thick covering stood many short circuit tests without any failure or sign of distress.

These tests established the fact that thin insulation on the conductor will not prevent such failures, even though it has sufficient dielectric strength to withstand the voltages placed across it for the reason that the magnetic force exerted on iron and steel objects will cause them to break through thin insulation. On the other hand, thick insulation will adequately protect the reactor from failure due to foreign substances.

Thermal Tests. *Thermal tests on the asbestos insulation established the following facts:*

First: That this insulation does not smoke excessively at temperatures below 350 deg. cent.

Second: That it does not burn even at temperatures of melting copper.

Third: That its insulation and mechanical strength is not appreciably affected when heated rapidly as high as 350 deg. cent.

Thermal Capacity. *The thermal capacity of the conductor is affected by the insulation, as follows:*

First: Under the effects of extremely high short circuit currents for a very brief interval, the thermal capacity is not affected by the asbestos.

Second: With a moderate short-circuit current for a longer length of time, the thermal capacity of the insulated conductor is increased due to the storage of heat in the insulation.

Third: During normal operation, at rated current, the temperature rise of conductor is increased due to the drop in temperature in the insulation.

Costs. *The asbestos insulation increases the cost of the reactor directly by the addition of the cost of the insulation itself and indirectly by making it necessary occasionally to increase the size of the conductor. However, this increase in cost is not a large percentage of the total cost of the reactor.*

* * * * *

IN a previous paper entitled, "The Design, Installation and Operation of Current Limiting Reactors," presented by Kierstead and Stephens, at the Annual Convention of the A. I. E. E., July 1924, short-circuit tests upon reactors were described. These tests proved conclusively that if conducting material were lodged between the turns of a reactor having bare conductor, the reactor would flashover at the instant a failure occurred on the circuit in which it was placed. In other words, if a piece of metal, such as a nut, bolt, washer, or screw drops or is magnetically drawn into a reactor and becomes lodged between two of its turns, there may be no indication of its presence in the reactor during the normal operation of the circuit but at the instant of a fault on this circuit, the voltage between these turns jumps to many times its previous value, incipient arcs shoot out at the points where the metal bridges between turns and this is followed instantly by a complete flashover of the reactor. Since that paper was presented, an investigation has been carried out to determine a suitable insulation for the conductor of reactors to prevent such foreign conducting material causing reactors to flashover. The purpose of this paper is to describe the tests which were made to determine the kind and thickness of insulation to be used.

The primary requisites of such insulation are as follows:

First: It must have sufficient dielectric and mechanical strength to prevent short circuits between turns by foreign conducting materials.

Second: It must conform to the well established practise of using only fire-proof materials in the construction of current-limiting reactors.

The first part of this paper is devoted to a description of the short-circuit tests made upon reactors to determine the insulation to be used, while the second part describes thermal tests made to determine the fire-proof characteristics of the insulation.

Short-Circuit Tests

Enamel and asbestos were chosen as the most suitable insulations because of their fire-proof characteristics. One reactor was built with enameled conductor and two reactors with asbestos-insulated conductors; one having a thin covering of asbestos, the other a thicker covering. The reason for making tests on reactors with these different insulations was to determine the thickness of insulation necessary.

The short-circuit tests made upon the reactors consisted of bringing up the terminal voltage on a 26,700-kv-a., 25-cycle generator to 13,200 volts, and then

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To be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926.

short-circuiting two of its phases through the reactor under test. All three reactors were the "cast-in concrete" type, rated: 60 cyc es, 68 kv-a., 229 volts, 300 amperes, and were designed for use in introducing 3 per cent reactive drop in a 13,200-volt circuit. A diagram of the connections used in the tests is shown in Fig. 1. The tests made upon the different reactors are described under the following headings: (A), Reactor with Enameled Conductor. (B), Reactor with a Thin Covering of Asbestos Insulation on the Conductor. (C), Reactor with a Thick Covering of Asbestos Insulation on the Conductor.

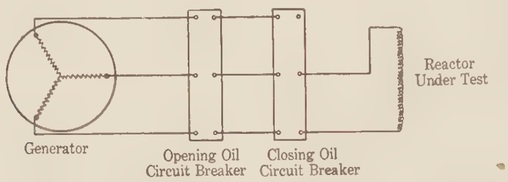


FIG. 1—DIAGRAM OF CIRCUIT USED WHEN MAKING SHORT CIRCUIT TESTS

A. Reactor with Enameled Conductor. The conductor of the reactor on which these tests were made was enameled and the purpose of the tests was to determine whether the enamel would afford sufficient insulation to prevent a flashover if conducting material bridged between the turns.

The test was made by placing a steel nut between two adjacent turns of the reactor midway between the top and the bottom and then short-circuiting the generator through the reactor. The reactor as it appeared immediately before the test is shown in the upper left hand corner of Fig. 2 which is an enlargement of a portion of the motion pictures taken during these tests. The nut is painted white and is clearly visible in the photograph.

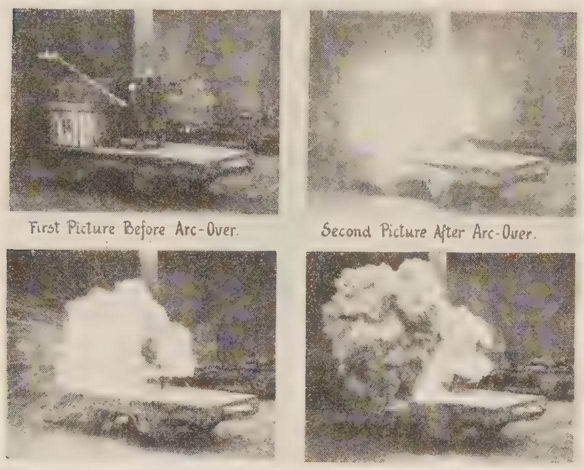


FIG. 2—REPRODUCTION FROM MOTION-PICTURE FILM TAKEN DURING SHORT-CIRCUIT TESTS ON REACTOR WITH ENAMELED CONDUCTOR

Arcing due to steel nut. *Enamel did not afford* sufficient insulation.

Although the reactor had previously been tested several times under short circuit (without giving any indication of distress), after the nut was placed in it, it flashed over during the first half cycle of the first short-circuit test. This test proved that enamel is not sufficient insulation to prevent a flashover, due to foreign conducting material.

The nut was thrown violently from the reactor to a distance of about 30 ft. where it struck a board and dented it to a depth of 1/16 in. In short-circuiting a portion of the reactor winding, the nut carried a current in opposition to the main current in the reactor and the magnetic force between these opposing currents was probably the propelling force which expelled the nut. In this respect, foreign conducting material partakes of lifelike characteristics in that it may cause a lot of damage and then clear out and leave no clue as to the cause of the damage.

B. Reactor with a Thin Covering of Asbestos on the Conductor. The reactor on which the tests under this heading were made had a thin wall of asbestos covering on its conductor. It received the same tests as those applied to the preceding reactor, except that in this case, a nail was tied to the conductor so as to span between the outside turns of the upper two layers. The reactor with the nail attached is shown in the upper left hand picture of Fig. 3 which is a reproduction of a portion of the motion pictures taken during this test. This reactor stood the first short-circuit test without showing any visible signs of distress but flashed over during the first half cycle of the second test. The other pictures shown in Fig. 3 immediately followed the instant of flashover.

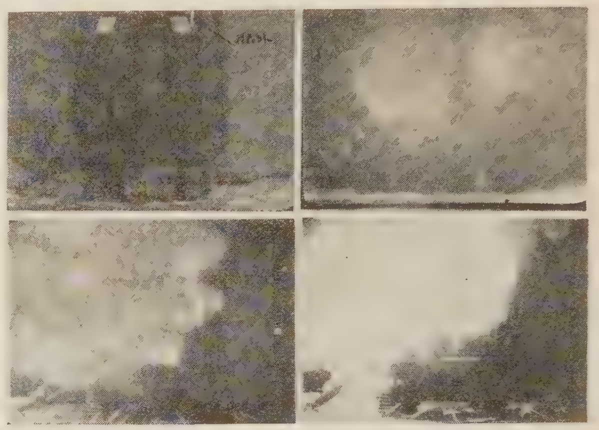


FIG. 3—REPRODUCTION FROM MOTION-PICTURE FILM TAKEN DURING SHORT-CIRCUIT TESTS ON REACTOR WITH CONDUCTOR INSULATED WITH THIN ASBESTOS

Arcing due to nail. Asbestos *was not thick enough* to afford sufficient insulation

These tests showed that while the thin asbestos covering afforded more protection than the enamel (since it was able to pass through one short-circuit test without failure) still it was not thick enough to adequately protect the reactor from foreign conducting material.

C. Reactor with a Thick Covering of Asbestos Insula-

tion on Its Conductor. The reactor tested next had thicker asbestos insulation on its conductor than that of the preceding reactor. Many short-circuit tests similar to those previously described were made on this reactor with steel bolts and nuts variously located in an endeavor to make the tests as severe as would be encountered in actual service. In this reactor, however, the insulation on the conductor was sufficient to afford

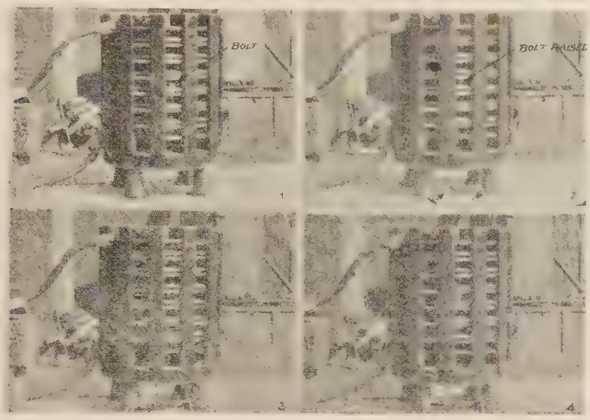


Fig. 4—Reproduction from Motion-Picture Film of Short-Circuit Tests on Reactor with Conductor Insulated with Thick Asbestos Insulation. Showing Bolt in Winding being raised and Nails being drawn toward Reactor by Magnetic Field. Arrows Indicate Nails

the conductor adequate protection from the foreign conducting material to which it was subjected. Some of the reproductions of the motion pictures taken during these tests are of interest, for the reason that having been taken at the rate of 125 pictures per second they show the movement of loose steel objects around and in the reactor. Fig. 4 shows four pictures taken

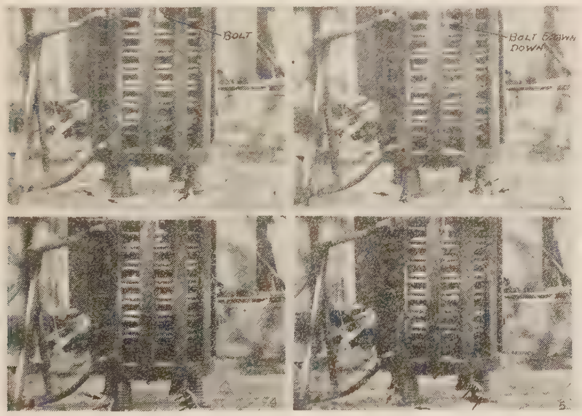


Fig. 5—Similar to Fig. 4 but shows Bolt being drawn by Magnetic Field from Top Layer to a Position Bridging between the Two Top Layers. Arrows Indicate Nails being drawn toward Reactor

when a loose bolt was placed on the winding midway between the top and the bottom. The pictures are consecutive in the order in which they are numbered. The first picture shows the bolt resting on the winding. The next picture taken 1/125 of a second later, shows one end of the bolt raised up by magnetic force so that it is striking against one of the turns above while the other end is resting on one of the turns below. The pictures also show nails which had been strewn on the floor near the reactor being lifted by the magnetic field. Fig. 5 shows a similar group of pictures except that the bolt is first resting on top of the winding but is later pulled down so as to span between the top and next adjacent layers. The picture again shows nails being lifted from the floor. In Fig. 6, the bolt was placed so that it spanned the space between the top and next adjacent layers before the test and did not move during the test. The chief interest in these latter pictures is that they show nai s being lifted from the floor and being drawn into the windings with considerable force.

The reproductions of the motion pictures show that

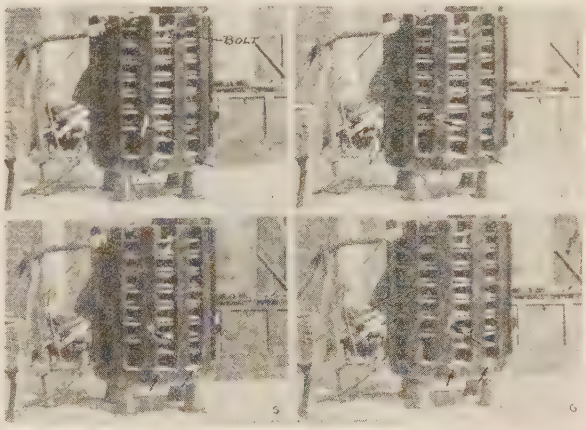


Fig. 6—Similar to Fig. 5 but shows Nails being drawn from Floor into Reactor by Magnetic Field. Arrows Indicate Nails

the magnetic field of a reactor exerts a considerable force on magnetic substances. Therefore, the insulation on the conductor not only must be strong enough to withstand the electric stress which may be placed upon it, but must also be strong enough mechanically to withstand without injury, the cutting or piercing action of iron and steel objects when drawn against it by the magnetic force. It was this latter action that was the primary cause of the failures of the first two reactors.

The thicker insulation on the last reactor tested had sufficient resilience to resist the blows delivered to it by the steel objects without being cut and in addition being thicker, could be indented to a greater depth without being pierced through to the conductor. Therefore, it was able to withstand the many short circuit tests it was subjected to without failure.

Summarizing, the foregoing tests established the following facts:

First: That a reactor with bare conductor will flashover during a short-circuit if conducting material is lodged in its winding.

Second: That thin insulation on the conductor will not prevent such failures, even though it has sufficient dielectric strength to withstand the voltages placed across it, for the reason that the magnetic force exerted on iron and steel objects will cause them to break through thin insulation.

Thermal Tests

Having established the thickness of asbestos insulation required to prevent electrical failures in reactors,

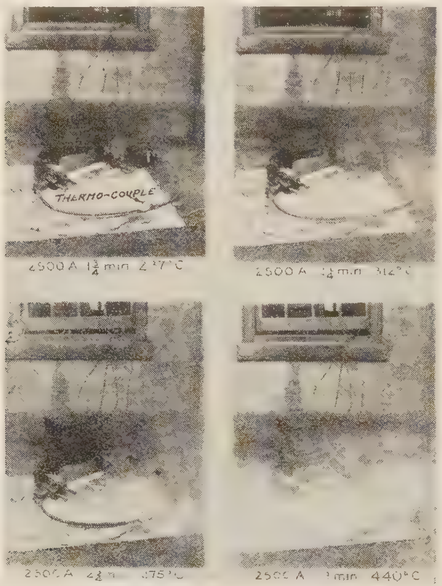


Fig. 7—Successive Pictures taken during High Temperature Test on Asbestos Insulated Cable.

it was next required to determine if this insulation was fire-proof.

Test to determine whether the insulation would burn were made on 5 ft. lengths of 250,000-cir. mil. cable insulated with asbestos insulation. The equipment used in making these tests is shown in Fig. 7 and is comprised of a transformer for use in obtaining high current, a current transformer for measuring the current, and a thermo couple placed in the center of the cable. The tests consisted of holding 2500 amperes in the conductor until it melted. The amount of smoke emitted from the cable during these tests is more clearly shown by Fig. 7 than can be described. The figure shows that smoke just began to make its appearance at 312 deg. cent. while it became most dense at 440 deg. cent. As the temperature increased above this figure, the denseness of the smoke gradually decreased and had discontinued before the melting point was reached. At no time did the insulation show any tendency to burn. After the cable had been raised to the melting point of copper, the binding materials which held the asbestos fibers together had been destroyed and as a result the mechanical strength of the asbestos was practically zero.

The next tests were made to determine to what temperatures the cable could be raised without damaging the asbestos insulation.

It was felt that the insulation should be cabable of resisting the effects of having the conductor rapidly heated up to a temperature of 350 deg. cent. without injury to its mechanical or electrical strength. Therefore, a test was made by holding 2500 amperes in the cable until 350 deg. cent. was reached. This required about 2½ minutes. The insulation showed no indication that its mechanical strength had been injured by this test and the puncture tests showed that its insulation strength had not deteriorated.

Summarizing, the foregoing high temperature tests have established the following facts:

First: That this asbestos insulation does not smoke excessively at temperature below 350 deg. cent.

Second: That it does not burn even at temperatures of melting copper.

Third: That its insulation and mechanical strength is not appreciably affected when heated rapidly to temperatures as high as 350 deg. cent.

In actual service with the reactor carrying full short-circuit current, there will be no tendency for the reactor to smoke or the insulation to be injured for the reason that the current will be interrupted by the circuit breaker long before the temperature of the conductor has risen to 350 deg. cent.

The question quite naturally arises as to what effect the asbestos insulation will have on the thermal capacity of the conductor. Of course, if a short circuit is maintained for such a brief period of time that prac-

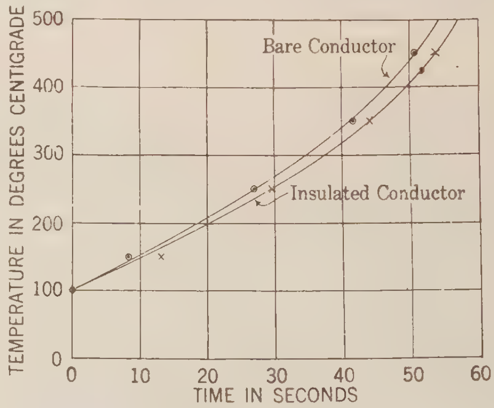


Fig. 8—Comparative Rate of Heating of Bare and Insulated Conductor for Short Periods

tically all the heat is stored in the copper then the insulated conductor will rise to practically the same temperature as the bare conductor. On the other hand, if the short circuit continues until an appreciable part of the heat generated is dissipated, there will be a period during which the flow of heat from the insulated conductor into its insulation will be more rapid than the flow of heat from the bare conductor into the air. During this period, the insulated conductor will be cooler than the bare conductor.

The accuracy of the above statement was checked by comparative tests on bare and insulated 250,000-cir. mil. cable. The tests consisted in holding 4000 amperes in each cable and measuring the time required for the conductors to rise to a given temperature. The temperature of the conductor was measured by thermo couples soldered to the conductor. In Fig. 8, the results of these tests are plotted. It will be noted that in all the tests the bare conductor was the hottest.

During the normal operation of the reactor when it is carrying rated current continuously, all the heat generated is, of course, dissipated and naturally the insulated conductor becomes the hottest. It has been found, however, that although asbestos is one of the best insulators of heat, the asbestos covering used on the conductors for reactors does not impede the flow of heat from the conductor to a great degree. The explanation for this is that the asbestos fibers are so

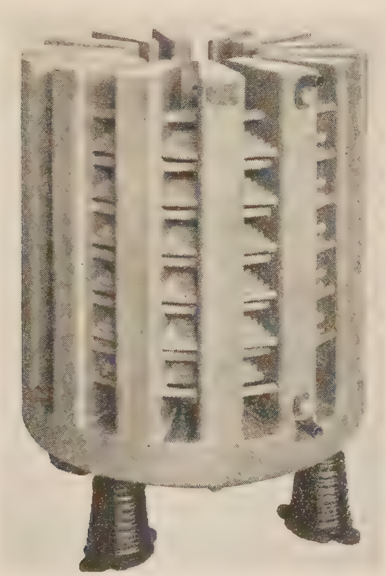


Fig. 9—"Cast-In Concrete" Reactor with Conductor Insulated with Asbestos Covering

densely formed around the conductor that the rate of conduction through them is many times more rapid than through the forms of asbestos used for heat insulation.

As has been shown in the preceding pages, the use of thick asbestos insulation removes the danger of flashover that a reactor without such insulation is subject to and yet does not affect its fire-proof qualities or the simplicity of its construction. Fig. 9 shows a reactor with asbestos insulation on its conductor. It will be noted that it is of the same general construction that has typified the "cast-in concrete" type of reactors for the past ten years. The asbestos fibers are closely and firmly woven on the conductor. They are treated with a compound which makes them very strong and able to resist cutting or tearing very tenaciously.

Insulating the conductors of reactors with asbestos increases their cost directly by the addition of the cost of the insulation itself and indirectly by making it necessary occasionally to increase the size of the conductor to compensate for the reduction in the rate of heat dissipation caused by the insulation. However, the cost of the insulation is not a arge percentage of the total cost of the reactor and the additional cost of a larger conductor is greatly offset by the reduced operating charges resulting from the reduction in losses occasioned by use of a larger conductor. Furthermore, as stated above, the asbestos covering has not been found to impede the flow of heat from the conductor to a great degree. These cost increases, therefore, are slight and will make no material difference in the present economies of a system which includes reactors.

In conclusion, attention is again called to the fact that the tests described in this paper have proven that any conductor insulation, which will afford adequate protection to a reactor from foreign conducting material not only must have sufficient insulation strength to stand the voltage stresses placed upon it, but also must have sufficient mechanical strength to withstand without injury the cutting and piercing action of iron or steel objects that may be drawn against it by the magnetic field of the reactor. Furthermore, the tests have shown that the asbestos insulation which has been developed for reactors affords protection from foreign conducting materials without sacrificing the fire-proof qualities which modern central station practise demands.

The author wishes to acknowledge the valuable assistance which Mr. L. P. Burgess rendered when the tests herein described were made.

PREVENTION OF DETERIORATION OF VULCANIZED RUBBER

It has been known for some time that deterioration of vulcanized rubber by oxidation can be delayed by the use of substances which are themselves easily oxidized and which act as anticatalysts of oxidation. Recently two of the largest rubber companies simultaneously patented almost identical antioxidants. A sample of the material received by the Bureau of Standards has been employed in rubber compounds which were then subjected to an accelerated aging test. The bureau's results substantiate the claim that the durability of rubber with respect to the effects of light and heat can be increased about 600 per cent.

Practical Aspects of System Stability

BY ROY WILKINS[1]

Associate, A. I. E. E.

Synopsis—*During the past few years there has been much discussion regarding the behavior of long transmission lines under transient conditions, such as flashovers, short circuits, arcs and grounds which would tend to make them unstable, but unfortunately this discussion has been largely theoretical due to the absence of any actual operating data upon which to base assumptions. It has only been recently that an opportunity has been afforded to make field tests on one of the two existing 220-kv. systems and the results of such a series of tests made on the system of the Pacific Gas and Electric Company are presented in the paper.*

This is the first instance where tests of this nature have been attempted and the lack of proper testing equipment proved a serious handicap. It was necessary to develop a special high-speed oscillograph wattmeter, a high-speed oscillograph filmholder and a pilot generator. Moreover the technique of testing was developed so that it was possible to secure oscillographic records 200 mi. apart by telephone signal.

The tests established the following important facts:

1. System stability as a problem is inextricably entangled with operating economics, and cannot be handled solely as a problem in design, except for very simple cases. 2. For any adequate conclusions to be reached much more fundamental data is necessary. 3. Requisite equipment for obtaining such data is not now available. 4. Studies of models and artificial transmission lines are not adequate because too little is known about the relative importance of the several factors to allow intelligent duplication. 5. Proper relay equipment and action is vital. 6. Oil-switch operation is an important factor. 7. Only a certain part of the stored energy of a system is available in any given case of trouble. 8. Operating distribution of excitation current is one of the major problems.

As transmission networks have grown in economic importance and kilowatt capacity, the problem of stable operation has assumed an increasingly greater importance, culminating in 1922-23 in studies of the proposed long distance transmission of large blocks of power to important market centers in the Atlantic States. In the consideration of these proposals a detailed study of system stability was considered essential. Preliminary theoretical analysis of the several problems encountered was presented at the Midwinter Convention of the Institute in 1924, and showed a decided lack of agreement on the methods of attack and the results obtained.

Opportunity was afforded to carry out tests on one of the two existing transmission systems having long 220-kv. transmission lines feeding a large load network, consequently a series of tests were carried out early in 1925 on the transmission system of the Pacific Gas and Electric Company to secure definite operating data on several of the points in question. The data accumulated on the test was an attempt to determine what was required on a network in order to predict its characteristics with respect to stability. It cannot be too strongly emphasized that data secured is for a specific condition on a given system and that such lack of agreement as evidenced in the calculations made in the past is due not so much to differences in mathematical treatment as to differences in assumptions made in regard to the relative importance of the several factors.

In the tests these factors are naturally included in their proper proportion and place, and any calculation made for the same conditions, to be at all adequate, must presuppose a thorough knowledge of all of the factors as well as of their relative importance. Artificial lines and miniature equipment cannot be substituted without such knowledge, for at best the results are

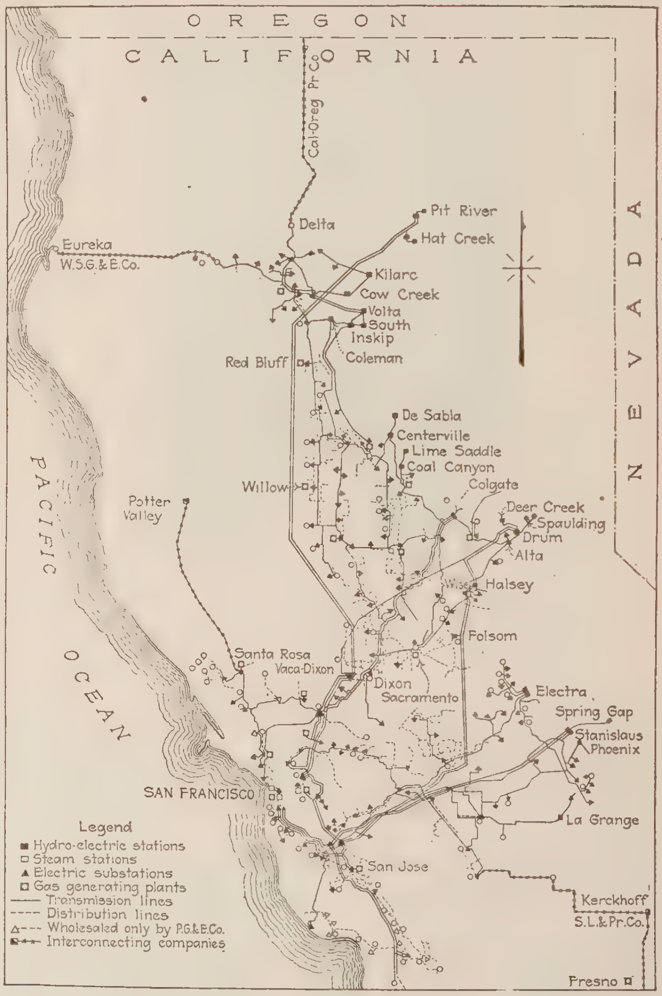


FIG. 1—SYSTEM DIAGRAM, PACIFIC GAS AND ELECTRIC COMPANY

only a reflection of the assumptions made. The difference between values in tests on an actual system and

1. Assistant Engineer, Division of Hydroelectric and Transmission Engineering, Pacific Gas and Electric Company, San Francisco, Calif.

To be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926.

calculated or miniature equipment tests represents the numerical value of errors due to such assumptions.

Given enough fundamental data on the network during trouble, the effect of such trouble may, with much patience and persistence, be calculated for very simple cases, but at least for the present the actual quantitative values for this fundamental data must be measured to insure any degree of accuracy in the final result. The tests as carried out are an attempt to evaluate at least a part of the unknown quantities, in order that the necessary assumptions for calculation may be at least reasonably correct.

Outline of Tests

The points on the system of the Pacific Gas and Electric Company selected for the tests were Pit No.1

TABLE I

NETWORK DATA AT TIME OF TEST

202 mi. of two-circuit 220-kv. line connected to three power-houses and one substation.
607 mi. of 110-kv. line connected to six power-houses and 10 substations.
2039 mi. of 60-kv. line, connected to 19 power-houses and 162 substations.
8434 mi. below 60-kv. line connected to 100 substations.
160 mi. of underground.
27—Hydro plants having 69 units and 317,975 kv-a. capacity.
4—Steam plants having 12 units and 142,000 kv-a. capacity.
2—20,000 kv-a. synchronous condensers.
2—12,500 kv-a. synchronous condensers.
1—7500 kv-a. synchronous condensers.

There were also, connected and operating in parallel, the Great Western Power Company, having
196 miles of 165-kv. line.
150 mi. of two circuit; 30 mi. of one circuit of 100-kv. line
520 mi.—below 60 and above 20-kv. line, with:
2—Hydro plants having nine units, 131,000 kv-a.
4—Steam plants having nine units 30,800 kv-a.
3—Synchronous Condensers having three units, 60,000 kv-a.

The California Oregon Power Company having 200 mi. of 66 kv.
513 mi. of 60 and 38 kv. with
10—Hydro plants having 16 units, 56,160 kv-a.

The Truckee River Power Company with five hydro plants and 8650 kv-a.

The Snow Mountain Power Company with,
107 mi. of line below 60 kv. and above 30 kv.
1 Hydro-Electric plant having 1 unit and 6400 kv-a. together with several smaller distributing networks to which the Pacific Gas and Electric Company wholesales power.

There was on the Pacific Gas and Electric Company system approximately 1,500,000 h. p. connected load, of which the average yearly distribution is:
35.0 per cent—Commercial and domestic lighting and heating.
13.5 per cent—Agricultural power (mostly centrifugal pumps).
3.0 per cent—Mining-power induction motors.
21.0 per cent—Manufacturing power.
8.0 per cent—Railway power.
19.5 per cent—Miscellaneous power.

The interconnected companies have roughly the same connected load per kv-a. generating capacity and the same general distribution of load.

For the Pacific Gas and Electric Company the monthly load factor in December is about 61 per cent, for August about 73 per cent, and the yearly load factor 62.5. The daily load factor is 65-79.

Power-House, the generator end of the two 202-mi., 220-kv. Pit transmission lines, and Vaca-Dixon Substation, the receiver end of these lines (see Fig. 1). Physical data on the system network at the time of the test is given in Table I.

Pit No. 1 Power-House has installed two 35,000-kv-a., 3-phase, 60-cycle, 11,000-volt generators driven by 40,000-h. p. Francis turbines, each having a $W R^2$ of 7,365,000 lb. ft. On the same 11,000-volt bus is also connected the two Hat Creek plants, each having one 12,500-kv-a. turbine-driven generator, with 2,800,000 $W R^2$, 6600-volt, 3-phase, 60-cycle connected through 6600- to 60,000-volt transformer banks and approximately five mi. of double-circuit tower lines to a step-down bank 60,000/1100 at Pit No. 1.

Connecting Pit No. 1 with Vaca Substation is a 202-mi. double-circuit 220-kv. transmission line,[2] through two 11,000- to 220,000-volt delta Y-connected 50,000-kv-a. transformer banks at Pit No. 1 and through two 200,000/110,000/10,460-volt 50,000-kv-a. banks at Vaca Substation. The Vaca transformer banks are Y-connected auto-transformers with a delta-connected tertiary from each of which is operated a 20,000-kv-a., 11,000-volt synchronous condenser. At Vaca the power enters the 110-kv. network as shown in Fig. 1. At the time of test, one line was operating at 220-kv. and one at 125-kv., one bank at Pit No. 1 being temporarily reconnected and the line going to the 110-kv. terminal of the bank at Vaca instead of the 220-kv., the 110-kv. is designated as No. 1 and the 220-kv. as No. 2.

The Following is an Outline of the Schedule of Tests.

I. *a.* Start condenser at Vaca.
   b. Trip one condenser at Vaca.

II. Run both generators at Pit, one leading and one lagging.
   a. Trip one.

III. Running both generators at Pit.
   Trip one at ¼ load.
   " " " ½ "
   " " " ¾ "

IV. Line switching at Pit.
   a. Switch out No. 2 line at Pit at 220 kv.
   b. " " " " " " Vaca at 220 kv.
   Vary and repeat.

V. Ground No. 2 line through fuse first tower out from Vaca bus.
   Repeat.

Test Equipment

A description of the equipment used in making the tests is given in Table II. The six-element oscillograph used at Pit No. 1 was a Westinghouse portable permanent magnet type equipped with a special film holder using 6½ in. films 24 ft. long and running up to speeds of about 1 in. per cycle. The 3-element was also a Westinghouse portable permanent magnet type with a special holder, handling films 3¼ in. by 15 ft. at speeds

2. See TRANSACTIONS A. I. E. E., 1924, Page 1148, Corona Loss Test.

TABLE II

TEST EQUIPMENT

Pit River No. 1 Power-House:

One 6-Element Oscillograph
One 3-Element Oscillograph
One 3-Element, 3-phase, oscillographic type wattmeter
One Motor-Generator Set for measuring absolute change in phase position
One Generator for showing rotor phase angle position
One Mechanical recording device to show governor action

Vaca-Dixon Substation;

One 3-Element Oscillograph
Two Recording Wattmeters
One Motor-Generator same as that used at Pit No. 1

Claremont Substation:

One Esterline Wattmeter

MEASURING THE FOLLOWING QUANTITIES

Line Switching—Angular Relations

Pit No. 1 Power-House:

Six-Element Oscillograph
One—Pilot Governor
Two—Motor Generator Set Voltage
Three—Generator Internal Voltage
Four—Vaca Voltage
Same zero line

Five—Generator Current
Six—No. 1 Line Current
Same zero line

Three-Element Oscillograph
One-Hat Creek Current
Two—Generator Terminal Voltage
Three—No. 2 Line Current

High Speed Wattmeter

1—Generator Power
2—Hat Creek Power
3—Line No. 1 Power

Esterline Wattmeter

1—Line No. 2 Power

Vaca Substation:

Three—Element Oscillograph
One—100 kv. Bus Voltage
Two—Condenser Current on Line No. 1
Three—Single Phase Wattmeter-No. 1 Condenser Power
Four—Differential 100 kv. Bus—Motor Generator Voltage

Esterline Wattmeter

One—Power Condenser on Line No. 2
Two—Drum line

Claremont Substation:

Esterline Wattmeter

Line Switching-Flux Relations

Pit No. 1 Power-House:

Six—Element Oscillograph
One—Pilot Generator
Two—Generator Terminal Voltage
Three—Generator Internal Voltage
Four—Generator Current
Same zero line

Five—Field Current
Six—Field Voltage
Same zero line

Three—Element Oscillograph
One—Motor Generator Voltage
Two—Vaca Voltage
Three—Generator Internal Voltage

High Speed Wattmeter

One—Generator Power
Two—Hat Creek Power
Three—Line No. 1 Power

Esterline Wattmeter

One—Line No. 2 Power
Three—Element Oscillograph

One—100 kv. Bus Voltage
Two—Condenser Current on Line No. 1
Three—Single Phase Wattmeter—No. 1 Condenser Power
Four—Differential 100 kv. Bus—M. G. Set

Esterline Wattmeters

One—Power Condenser on Line No. 2
Two—Drum Line

Claremont Substation:

Esterline Wattmeter

Single Phase—Short Circuit

Pit No. 1 Power-House:

Six—Element Oscillograph
One—Pilot Generator Voltage
Two—Motor Generator Voltage
Three—Generator Internal Voltage
Same zero line

Four—Generator Current
Five—No. 1 Line Current
Six—Hat Creek Current
Same zero line

Three—Element Oscillograph

One—Residual Current
Two—Generator Terminal Voltage
Three—No. 2 Line Current

High Speed Wattmeter

One—Generator Power
Two—Hat Creek Power
Three—No. 1 Line Power

Esterline Wattmeter

One—No. 2 Line Power

Vaca Substation:

Three—Element Oscillograph

One—Residual Current—3—220 kv. Bushing Transformer
Two—Positive sequence voltage
Three—Single phase wattmeter—el No. 1 and el No. 4
Four—Residual Voltage

Esterline Wattmeters

One—Power of Condenser on Line No. 2
Two—Power on Drum Line

Claremont Substation:

Esterline Wattmeter

up to 1 in. per cycle. The oscillograph wattmeter was a moving coil instrument having three single-phase elements operating one mirror with straight line charac-

FIG. 2—POLYPHASE ELEMENT OF OSCILLOGRAPHIC WATTMETER

teristics and a natural period of about $^1/_{20}$ second; developed by the Westinghouse Company for the test, see Fig. 2, calibration Fig. 3.

There were three of these 3-phase meters in one case,

all working on the same film. Timing was accomplished by interrupting the beam of light from one meter for a short time every $^1/_{10}$ second by means of a small synchronous motor, giving indications shown as small gaps in the record of one meter on the film. The films were $3\frac{1}{4}$ in. by 55 in. and had a speed up to 15 in. per second. For measuring the absolute change in phase position a small motor-generator set comprised of a d-c. motor and an alternator with a fly-wheel was run from the station storage battery. There was

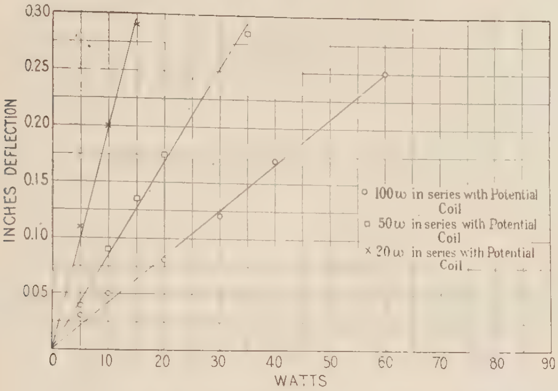


Fig. 3—Calibration of Same (Single-Phase)

Fig. 4—Pilot Governor

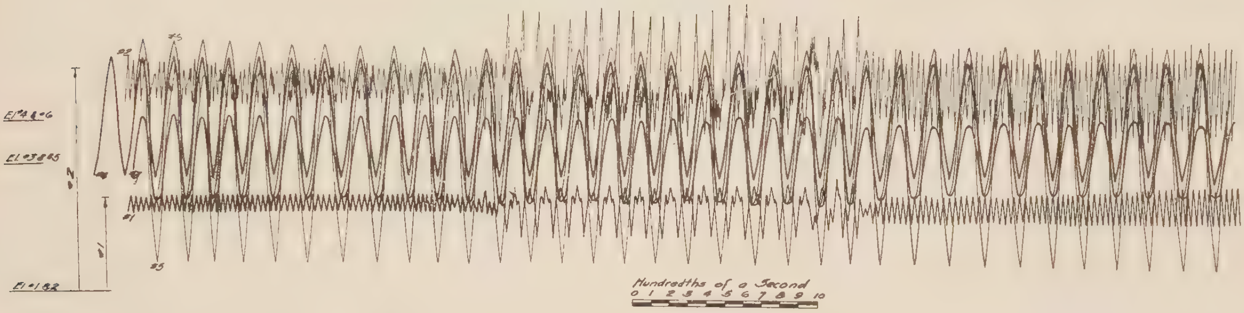


Fig. 5—Section of 24-Ft. Film of a 6-Element Oscillograph

Stability tests at Pit River Power House No. 1, June 18, 1925, 11:40 p.m.

El. No. 1—Field Voltage El. No. 4—Rotor Voltage
No. 2—Field Current No. 5—Gen. Terminal Voltage
No. 3—Generator Current No. 6—Gen. Internal Voltage

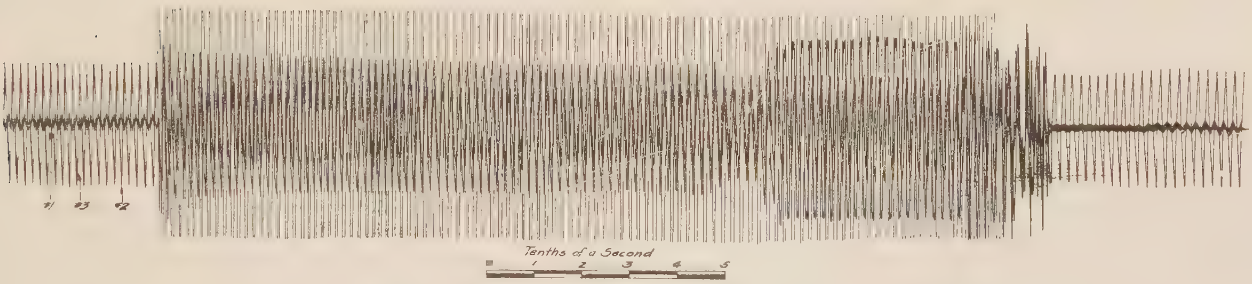


Fig. 6—Section of 15-Ft. Film of a 3-Element Oscillograph at Pit No. 1 during Flashover

Stability Tests at Pit River Power House No. 1, June 18, 1925

El. No. 1—Residual Current No. 2—Gen. Voltage No. 3, No. 2 Line Current, $B\ \phi$

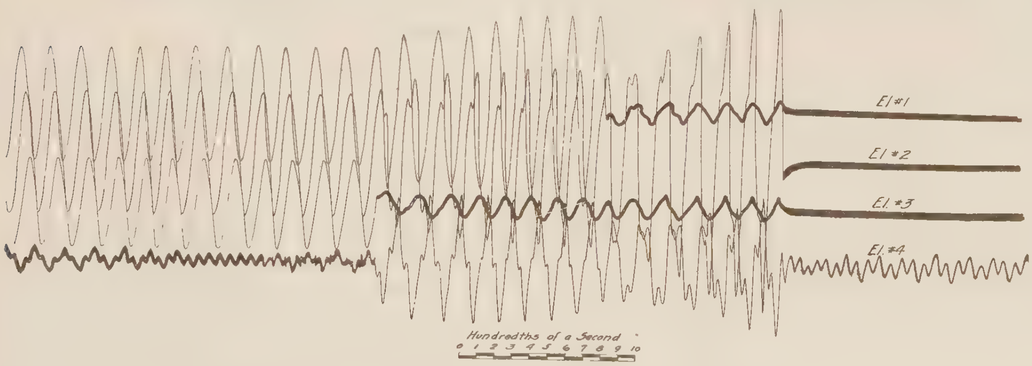


Fig. 7—Film of Oil-Circuit Breaker Action

Stability Tests at Pit River Power House No. 1, June 18, 1925, 10:35 p. m.

El. No. 1—No. 2 Line Current $C\ \phi$ El. No. 3, No. 2 Line Current, $A\ \phi$
No. 2—No. 2 Line Current $B\ \phi$ No. 4 Residual Current

mounted on the generator, with its rotor mounted on the end of the generator shaft, a remodeled "Ford" magneto having the same number of poles as the main generator, (see Fig. 4). This magneto having no load, gave a true record of the field or rotor position at all times and its wave is referred to as the pilot generator voltage. There was also installed a mechanical recording device on the turbine governor giving governor travel.

The 3-element oscillograph used was a Westinghouse electromagnet portable oscillograph, having in addition to the three elements, a single-phase wattmeter using the fourth prism and the same film. The film was 3¼ in. by 55 in. and was run at speeds up to 15 in. per second. There were also two special polyphase graphic wattmeters using high speed charts driven by synchronous motors. All of the data at Vaca was taken by telephone signal from Pit No. 1 as was also the switching. This was satisfactory enough that the two sets of equipment 200 mi. apart were able to catch each test on the standard film within one-quarter of its travel.

Fig. 8—Oscillographic Wattmeter Record of Opening One Line
Stability Test at Pit River Power House No. 1, June 17, 1925, 11:40 p. m.
El. No. 1—No. Gen. Power No. 2—Hat Creek Power No. 3—No. 1 Line Power

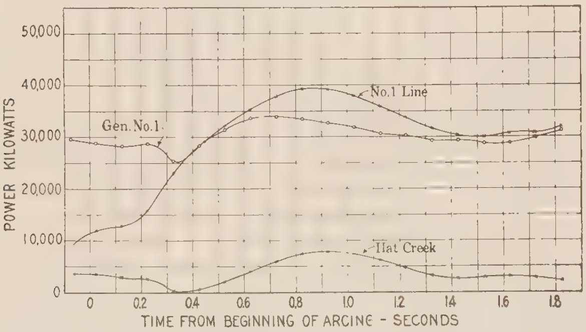


Fig. 9—Fig. 8 Plotted to a Common Scale for All Elements

transient and a speed sufficient to make individual cycles available for angular measurement.

Fig. 5 represents that portion of a 24-ft. film during which switching took place, for opening a 220-kv. line at Pit No. 1.

Fig. 6 is a portion of a 15-ft. film taken at Pit No. 1 Power-House during one of the artificial flashovers at Vaca Substation.

This shows the start of the flashover, the point at which the line cleared at Vaca, the point at which Pit No. 1 cleared, and on the original film 7 or 8 seconds record thereafter.

Fig. 7 shows a portion of a film of an oil circuit breaker opening a 220-kv. line lightly loaded. There are shown the three line currents and the residual current.

This record indicates the phase balance action between phases when opening a polyphase circuit; the current ruptured by the last circuit breaker shows nearly four times the original phase current.

Fig. 8 is the record by the oscillographic wattmeter of switching out the 220-kv. line at Pit No. 1 carrying 24,000 kw., thereby increasing the load on the 110-kv. line from 12,000 to 35,000 kw.

The generator instead of dropping from 32,000 kw. to 12,000 kw. drops only about 3000 kw., and that only after $^{3}/_{10}$ second.

Fig. 9 shows these wattmeter records plotted on a common scale.

Fig. 10 shows the reverse process, *i. e.*, closing the 220-kv. line at Pit No. 1 and picking up load from the 110-kv. line. This action is much more severe, takes place faster and causes more outside disturbance than the opening of a line.

Fig. 11 shows this plotted to a common scale.

Previous articles[3] on this subject have considered that

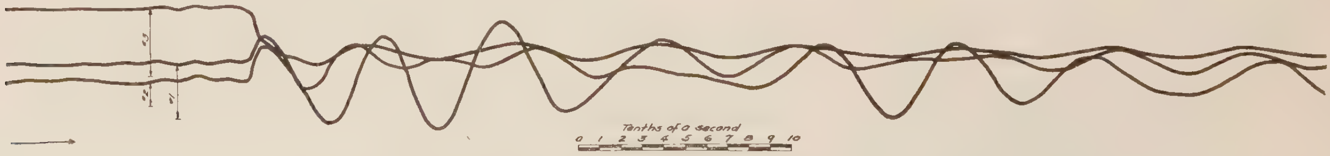


Fig. 10—Oscillographic Wattmeter Record of Closing One Line
Stability Tests at Pit River Power House No. 1, June 18, 1925, 12:12 a. m.
El. No. 1—No. 1 Gen. Power No. 2—Hat Creek Power No. 3—No. 1 Line Power

Character of Data

It was necessary that the preliminary data be taken comparatively cheaply and without undue disturbance to normal operation, that the oscillographic records have a length in time sufficient to cover all of the when one of two parallel lines was opened, the output of the station feeding them dropped instantly to the load on the remaining line while the prime mover stored

3. See J. P. Jollyman, Journ. A. I. E. E., Sept., 1925, p. 950, Fig. 4. C. L. Fortescue, Jour. A. I. E. E., Sept., 1925, p. 955, Fig. 4.

energy in the fly-wheel effect of the generator, releasing it to cause as great an overswing of output as the drop represented in kw. hrs.

This view assumes that the energy absorbed must be shown in a change in velocity of the generator rotor caused mechanically by the prime mover, and that there is no damping action. The curves demonstrate that such is not the case and also that closing a line more nearly approximates it than opening one.

In the writer's opinion the same effect is obtained by changing the power-factor of the generator load because this gives the same shift of the generator rotor and rotating armature field as a change in rotor velocity would, with the addition that it can take place as fast as circuit conditions permit. For a generator carrying load, the field poles occupy a certain position with respect to the rotating armature flux, any increase in load causes the armature flux to lag behind the field poles, *i. e.*, to come from the trailing edge of the pole if the power is constant. Given a constant load, a change in power-factor accomplishes the same result.

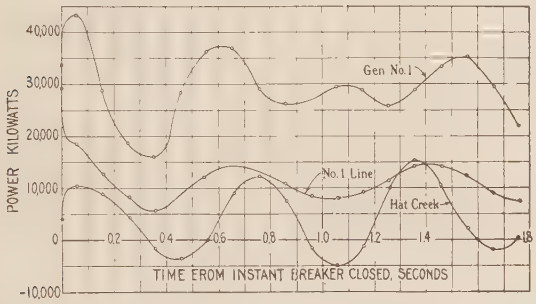


Fig. 11—Fig. 10 Plotted to a Common Scale for All Elements

With such a pilot generator as used at Pit No. 1, these changes may be observed on an oscillograph. Any such shift in armature flux position absorbs from or delivers energy to the field structure rotating as a fly-wheel and it must take place before there is any tendency to change the speed of the prime movers.

The rate at which energy can be absorbed depends on the electrical characteristics of the circuit involving a great number of variables among which is oil-circuit breaker action. No circuit breaker at present in use interrupts a circuit instantly, neither do they interrupt all three phases simultaneously because they interrupt the circuit at the zero point on the current wave of an arc of variable length. When closing the contacts make contact mechanically at a predetermined position and the action is, therefore, much quicker and more uniform. All of these things cause a change in wave shape in both current and voltage in all of the interconnected circuits. In most of the tests described, the speed and length of film were sufficient to permit angular measurement to be taken.

It was found that the change in wave shape was sufficient to materially affect the results.

On one of the tests, shown by Fig. 12, the several waves have been analyzed for fundamental, third and fifth harmonics and the angular position of the fundamental with respect to the actual wave determined.

TABLE III

Harmonics Present During Artificial Flashover at Vaca

(See Figs. 12 to 17)

Wave	Per Cent Harmonics	Angle from Actual Wave
Terminal voltage before transient...	99.8 1st	−1.2
	3.5 3rd	12.0
	5.1 5th	7.9
Terminal voltage 0.3 sec. after transient......................	99.4 1st	1.0
	7.9 3rd	18.6
	6.9 5th	−3.8
Terminal voltage 0.95 sec. after transient......................	99.2 1st	−1.5
	10.4 3rd	20.9
	7.4 5th	−7.1
Terminal voltage 1.2 sec. after transient......................	99.3 1st	0
	9.4 3rd	16.6
	7.6 5th	−4.7
Generator current before transient..	100 1st	+2.8
	.5 3rd	−12.5
	.4 5th	38.5
Hat Creek current before transient...	99.6 1st	−2.8
	3.8 3rd	35.9
	7.9 5th	4.0
Hat Creek current 0.40 sec. after transient......................	98.1 1st	−11.9
	4.8 3rd	27.4
	18.8 5th	18.9
Hat Creek current 0.7 sec. after transient......................	99.6 1st	7.1
	5.3 3rd	−27.6
	7.1 5th	−3.0
Hat Creek current 1.3 sec. after transient......................	99.6 1st	−3.2
	1.7 3rd	22.8
	8.2 5th	27.2

Fig. 13 gives a polar diagram of the generator terminal voltage before the transient; Fig. 14, the same wave $^7/_{10}$ second after the transient.

Fig. 15 Hat Creek current before the transient. Fig. 16, $^7/_{11}$ second after and Fig. 17 $1^3/_{10}$ seconds after the transient.

Table III, by S. B. Griscom of Westinghouse Electric and Manufacturing Company, gives the numerical values of these harmonics and angles in this particular test.

Fig. 18 shows an oscillographic wattmeter record of an artificial flashover on the 220-kv. line under normal operating conditions caused by closing an air switch; Fig. 19, on a string of insulators over which a 10-ampere fuse had been placed.

This gave an arc from one phase to ground over an insulator string cleared by relays in the normal manner under actual operating conditions.

Oscillograms of current, voltage, etc., were taken both at Pit No. 1 Power-House and Vaca during such a flashover. Fig. 20 and Fig. 21 are illustrations of such an arc.

At Vaca, in addition to the oscillographic record of current and voltage, there was a single-phase wattmeter record of the residual power, *i. e.*, voltage across the corner of an open delta and the common return of the three current transformers connected in Y.

Fig. 22 shows the record for two such flashovers.

Too strong emphasis cannot be placed on the statement that any such data is for a network in operating condition, and that there are a great number of unknown variables involved, the determination of any one of which is a problem of major importance, worthy of a complete discussion in itself.

The stability problem is inextricably enmeshed with system operating economies and in the greater number of cases the limitations are as much operating difficulties as engineering design. It is not possible to economically build and operate a complete superpower network for ideal conditions at the present time. Such networks grow naturally from the demand for more and better power service, and are made up of interconnected existing networks too valuable to junk outright. They must be adapted to operate together.

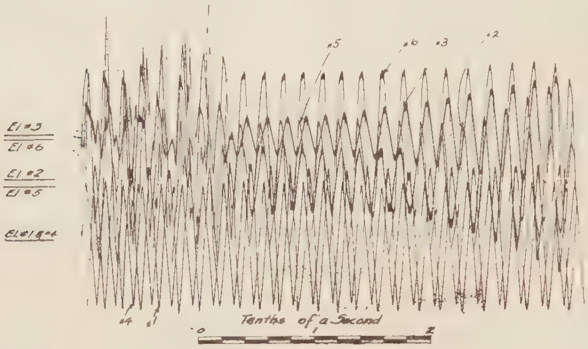


FIG. 12—SECTION OF 24-FT. FILM OF A 6-ELEMENT OSCILLOGRAPH AT PIT NO. 1 FOR ARTIFICIAL FLASHOVER AT VACA

Stability Tests at Pit River House No. 1, June 19, 1925, 1:20 a. m.

El. No. 1—M. G. Set Voltage
No. 2—No. 1 Line Current
No. 3—Generator Current
El. No. 4—Rotor Voltage
No. 5—Vaca Voltage
No. 6—Gen. Int. Voltage

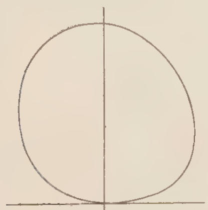


FIG. 13—POLAR DIAGRAM OF GENERATOR TERMINAL VOLTAGE BEFORE TRANSIENT

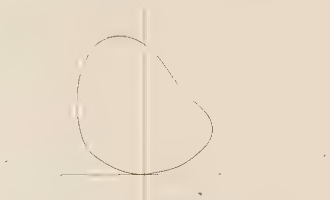


FIG. 14—THE SAME AS FIG. 13 BUT 7/10 SECOND AFTER THE TRANSIENT

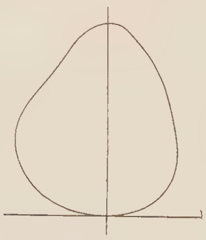


FIG. 15—POLAR DIAGRAM OF HAT CREEK CURRENT BEFORE TRANSIENT

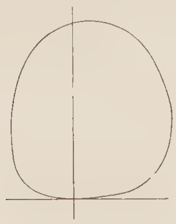


FIG. 16—SAME AS FIG. 15 BUT 7/10 SECOND AFTER THE TRANSIENT

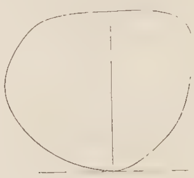


FIG. 17—SAME AS FIG. 15 BUT 1 3/10 SECONDS AFTER THE TRANSIENT

NECESSARY CONSIDERATIONS

Trouble, Relays and Switching. On any major line in a network similar to the one on which these tests were made, it is *absolutely essential* to clear arcs quickly; so quickly in fact that neither governors nor automatic voltage regulators of the present type can act sufficiently to make any material change before the line is cleared. With proper relay action a line can be cleared of an arc over an insulator string so promptly that it has been almost impossible to locate the point of trouble. If an arc is left unchecked for anything like the time required for the network to reach a stable condition, the wire in trouble is melted or sufficiently annealed to cause it to part mechanically. Arcs on high tension lines generally strip the top and bottom units of an insulator string first and then cause a burn sufficient to drop a conductor. On any line of 220 kv. the conductor size and stringing tension make it necessary to have heavy equipment, usually gasoline-driven trucks, to handle any work done on the conductors. For this reason it is necessary to clear positively and quickly any trouble. Failure to do this means not a momentary interruption but hours, or more probably days, until the necessary heavy equipment can be assembled at the point of trouble for line repairs.

Experience has shown that the only practical procedure is to clear the smallest practical section of the network around the trouble in the shortest possible time.

FIG. 18—AN OSCILLOGRAPHIC WATTMETER RECORD OF AN ARTIFICIAL FLASHOVER ON THE 220-KV. LINE

Stability Tests at Pit River Power House No. 1, June 19, 1925, 2:15 a. m

El. No. 1—No. 1 Gen. Power No. 2—Hat Creek Power No. 3—No. 1 Line Power

TABLE IV

ANALYSIS OF RELAY OPERATION ON THE 220-KV., 110-KV., AND 60-KV. TRANSMISSION NETWORK OF THE PACIFIC GAS AND ELECTRIC COMPANY FOR 1923 AND 1924

1		2		3		4		5		6	
Total operations involving relays		Correct relay operations		Relay failures		Incorrect relay operations: Due to relay		Incorrect relay operations: Due to external causes		Questionable relay operations	
Year	No.	No.	Per Cent	No.	Per Cent	No.	Per Cent	No.	Per Cent	No.	Per Cent
1923	1,593	1,490	93.6	24	1.5	11	.7	40	2.5	28	1.7
1924	1,884	1,699	90.2	31	1.6	3	.2	108	5.7	43	2.3

Col. 1—Relay Failures (No Operation of Switch)

Under this heading are listed all cases where subsequent investigation has proved that conditions at the point in question were such as to permit correct relay operation but the relays failed to function. No case is listed as a relay failure if investigation proved the trouble to be due to a break, ground or other fault in the direct-current tripping circuit, or to mechanical defect in the switch or auxiliary apparatus external to the relay itself.

Col. 2—Total Relay Operations

This tabulation includes all cases of relay operation causing the opening of oil switches and is a summation of Cols. 3, 4 and 5. (Note—Cases of relay operation due to accidental shorting or closing of contacts are not included in this report).

Col. 3—Correct Relay Operations

Under this heading are listed all relay operations which have been proved to be correct under the conditions existing at the time. This tabulation includes many cases which were not entirely satisfactory from an operating standpoint, but where, owing to load, voltage and power-factor conditions, it was necessary to give the relays credit for correct operation, even though the results were not precisely as desired. There are also included in this table a number of cases in which unsatisfactory relay operation has occurred due to inadequate equipment. (See Col. 4) In all these cases, however, the relays themselves functioned correctly under the circumstances.

Col. 4—Incorrect Relay Operations Due to Relay

This tabulation includes all cases that have been proved by subsequent investigation and test to be due to faults, either mechanical or electrical, in the relays themselves. (Note—This classification does not include relay operations which were apparently faulty because of inadequate equipment or improper connections.)

Col. 4—Incorrect Relay Operations Due to External Causes

Under this classification are listed all cases of relay operation which investigation has shown to be the result of faults or improper connections in auxiliary apparatus external to the relays themselves.

Col. 5—Questionable Relay Operations

This table covers relay operations which it has been found impossible to classify under Col. 3 or 4. In most cases the operation has been unsatisfactory, but owing to the lack of evidence it was considered unfair to classify it as incorrect, particularly as a test made after the trouble showed the relays to be operating correctly so far as could be determined.

In Table IV is given the high tension relay operations for 1923 and 1924, and in Chart V is given the segregation of all high-tension troubles for the year 1924.

Of manual switching for 182,500 switching operations on the Pacific Gas and Electric Company system in a year, 23 caused trouble.

The greater portion of the high voltage troubles are phase-to-ground arcs caused by conditions fairly well known and to a considerable extent avoidable.

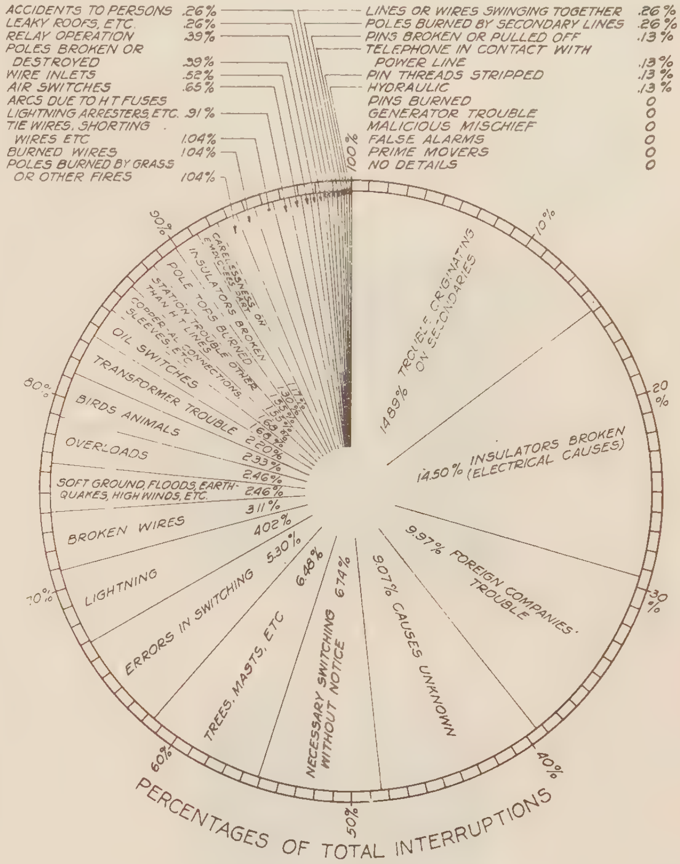
Insulation in any reasonable amount is not a positive insurance against direct strokes of lightning, severe storms or certain birds and no amount is proof against occasional man-made failures.

Stored Energy and Governing

The stored energy or fly-wheel effect of the rotating

TABLE V

Analysis of System Troubles, Pacific Gas and Electric Company



DIAGRAMMATIC ANALYSIS OF TRANSMISSION SYSTEM INTERRUPTIONS
PACIFIC GAS AND ELECTRIC COMPANY INCLUDING LEASED PROPERTIES
1924

equipment on the network varies from 2350 ft-lb. per kv-a. in the larger hydro-electric units to 1195 ft-lb. per kv-a. in some of the smaller high speed units and typical steam turbo alternators. Typical steam turbo alternators have about 5500 ft-lb. per kv-a.

Fig. 19—Air-Switch Arrangement for Closing a Ground on the 220-Kv. Line

The effect of the rotating equipment connection as load is very difficult to determine but it was in the order of 20 per cent of the effect of the generating equipment on the network.

At any given point on the network only a certain portion of this energy is available in a case of switching

or trouble, varying for 3-phase, single-phase and phase-to-ground troubles in the same manner that the short circuit kv-a. varies as far as the distribution over the network is concerned, but the energy delivered is dependent on the rate of change of speed and also on the line and equipment characteristics.

Experience has demonstrated that for a load of 300,000 kw., a drop from 60 cycles to 59 cycles will drop the load about 3.5 per cent, while an increase of from

Fig. 20—Photograph of a 220-Kv. Arc during the artificial Flashover

Fig. 21—Same as Fig. 20 from a Different Direction

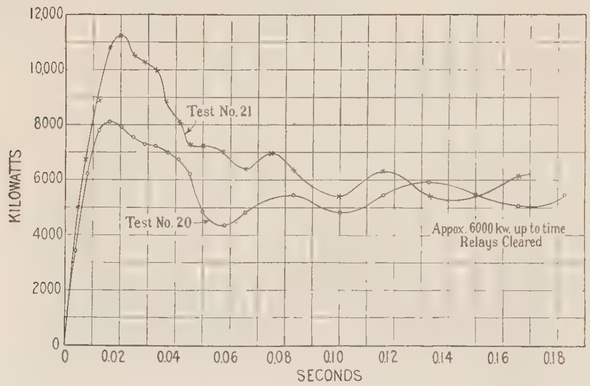


Fig. 22—Residual Power in Artificial Flashover

60 to 61 cycles increases the load about 4 per cent. This is due to the character of the load, some of which varies with the cube of the speed and some of which has no variation with speed. The actual percentages vary slightly therefrom with the season. The network is somewhat self-governing and the actual governing is done on one unit in a designated plant with all the remaining plants carrying block loads.

There are two methods of accomplishing this result:

1. Setting all governors on a flat speed characteristic to reject load at approximately ½ cycle above normal speed with a load limit set for a block load on all but the one governor used for regulation on turbines or a given nozzle opening on impulse wheels. Then as the speed varies too near the limit of the governing unit add to or reduce the block load to keep the governing unit in action.

2. Set all governors with a drooping speed characteristic and change the governor setting as load increases or decreases in the manner of the synchronizing motor on a steam turbine.

The Pacific Gas and Electric Company network uses the first on hydro-units and the second on steam, although various combinations have been used in the past.

On the network described above with the present system of relaying,[4] the speed does not drop enough during switching or trouble for the governors to act until after the switching is over. This is true for several reasons:

First, it is not possible to deliver sufficient kv-a. at any given point in the network to drop the speed fast enough to get governor action during the time it takes to clear trouble.

Second, governors, particularly on hydro units, have an operating time determined by the equipment controlled, *i. e.*, turbines, relief valves and penstocks, and this is of necessity a matter of several seconds.

All governors in general use today are used for holding speed and nothing else, and are, therefore, of necessity actuated only by speed. Particularly on hydroelectric units not having a means of by-passing the unit, the governors are definitely limited in action by penstock pressure rise, and are, therefore, a compromise between the cost of generators to stand overspeed and overvoltage and penstocks to stand over-pressure.

Charging Current

Charging current on high-voltage lines plays an important part in system stability, and a considerable portion of the reported cases of instability are in fact improper operation. An example of this effect is shown in the tests where it was demonstrated that switching out a 220-kv. line at Vaca Substation and allowing it to trip on over voltage at Pit No. 1 was the most severe condition encountered as regards stability. This has also been checked in actual operation several times. It is due to the action of the line free at one end with nearly 30,000 kw. of corona loss and a leading current in the generator at Pit No. 1 Power-House. The voltage rises at Pit No. 1 Power-House in about 5 cycles and the line relays out in approximately over ¾

4. See *Electrical World*, November 22, 1924.

second under such conditions. In this connection must be considered the excitation characteristics of the generators and the manner and direction from which the charging current is supplied, *i. e.*, either from the system network and receiving-end condensers or from the generators themselves.

a. Corona. Corona load on long 220-kv. lines under certain switching conditions may be several thousand kilowatts and must be considered in stability problems.

b. Phase Balancing. On all 220-kv. switches so far installed and operated the difference in opening time of the three phases varies from 5 to 20 cycles and allows an interchange of power between phases as well as a damping action in the arc.

c. Impedance. Intimately connected with all network disturbances is the system impedance to the point in trouble. This, to be accurate, must include all the connected equipment with its proper characteristics, in most cases transient characteristics, because present-day operating practise developed by trial has demonstrated that the relay equipment must be able to separate equipment and lines in trouble in a time measured in seconds or parts of a second, or the damage done will permanently disable such line or equipment.

Very little is known about transient impedance values, particularly single-phase or phase-to-ground impedances. For most networks such data are not available nor has any practical method been developed for obtaining it.

The oscillographic wattmeter used on the flashover tests in this connection is believed to be an innovation in this respect.

All changes of load caused either by switching or grounds and short circuits are taken up in the network by a transient condition causing a change in speed followed by a readjusted steady state either at a new speed or at the same speed and new loads on one or more units.

The amount of speed change is dependent on the rate at which the stored energy can be absorbed at the point of trouble, and this in turn is dependent on the impedance which is varied by all of those things that affect the short-circuit problem, together with the character of the trouble, the excitation on the rotating equipment, charging current, corona and those things which go to make up the speed load characteristics of the network.

Conclusion

These tests represent the initial attempt to secure data of this character on a large network in actual operation. The manner of using such data and the results obtained therefrom are given in the companion paper by Evans and Wagner who were instrumental in furnishing both personnel and equipment for the tests thus far made.

CORRESPONDENCE

LEAKAGE REACTANCE

To the Editor:

I wish to take vigorous exception to Mr. Boyajian's statement in his closing discussion[1] on his paper, Resolution of Transformer Reactances, etc., that I "seem to be in agreement with the speaker on the main points of the paper." I had no such intention, and Mr. Boyajian has evidently misunderstood my discussion. In fact my position on this question of leakage reactance is entirely opposed to that set forth by Mr. Boyajian. Now it *seems* to me that he has fallen into error on account of the fact that the same "equivalent" circuit may be used to represent the behavior of a two-winding transformer, in which the exciting component of current is *not* neglected; or of a three-winding transformer, in which the exciting component of current is neglected. Since certain relations can be shown to exist in the latter case he argues that the same relations hold true in the former. This logic is entirely erroneous. As a matter of fact the conflicting views that have been expressed are occasioned by different conceptions of what leakage reactance really is. It seems to me that it would be very unfortunate if we were forced to use one value of leakage reactance when considering one component of current and a different value when considering another component; especially so, since the various components are, in reality, nothing but figments of the imagination. This, however, is Mr. Boyajian's conception for he says, "The burden of my paper was to show that the leakage reactance which a winding offers to exciting current is different from that which it offers to a load current, similar, etc."

Of the half dozen books which I have just consulted I find none that supports this view. The late Dr. Steinmetz, for example, in discussing the transformer assigns a definite leakage reactance to the primary and another definite leakage reactance to the secondary. There appears to be no question whatever of using one value of leakage reactance for an exciting component and a different one for a load component.[2] A good exposition of this point of view will be found in "Principles of Alternating Currents," R. R. Lawrence. The definition there given for the leakage inductance of winding No. 1 with respect to winding No. 2 is the difference between the self-inductance of winding No. 1 and the mutual inductance between windings Nos. 1 and 2 multiplied by the ratio of the turns. The leakage reactance of one winding is always given with respect to some other winding. It is not a function of one winding alone but of two windings. In this respect it is like mutual inductance. Of course, in a commercial transformer the self and mutual inductances are variable but their difference as described above is essentially constant except possibly under some extreme condition

1. A. I. E. E. Journal, October 1925, page 1140.
2. "Alternating Current Phenomena," C. P. Steinmetz.

of core saturation, inasmuch as the leakage-flux linkages of one winding with respect to the other must be due to flux that exists at least partly in air. Here I wish to emphasize most strongly that in general reactance is not a function of any particular current but depends solely upon the configuration of the electric circuit or circuits considered and the neighboring magnetic material and its condition. In general the condition of this magnetic material depends upon *all* of the currents and not upon any one or upon any component of any one.

So far as I am aware, any problem that depends upon variable reactances can be handled only by making suitable approximations. There is no doubt that the leakage reactance of one winding of a transformer with respect to another may be different with different core saturations. However, I have never seen any reliable data tending to show that these differences are significant. And even if they did exist, it would not mean that one value of leakage reactance should be used with one component and a different value with another component of current, as Mr. Boyajian implies.

With the foregoing conception of leakage reactance, the vector difference in potential between the primary and secondary potentials of a one-to-one two-winding transformer is the vector sum of the individual leakage-impedance drops in the primary and secondary windings. This use of vectors assumes that the currents are essentially sinusoidal. Ordinarily we assume that the two currents are equal, in which case the "equivalent" leakage reactance is the numerical sum of the individual leakage reactances. It is only when the exciting current is neglected, however, that this summation is allowable.

Now there is another point in this connection that Mr. Boyajian seems not to consider when he proposes his first test. It is that reactance can usefully be defined as the ratio of volts to amperes only when the wave form of the current is sinusoidal. For example, the third-harmonic component of drop in this test is probably much larger than the fundamental component. The test is therefore valueless without the wave form of exciting current, and even if this is known the accuracy is rather poor and the computation rather cumbersome. This same comment in regard to wave form of current applies to Mr. Boyajian's test No. 5. Prof. Dahl mentions this and I am entirely in agreement with him. The small variation that Mr. Boyajian noticed might be due either to transformer unbalance, as Prof. Dahl suggests, or to an actual change in the leakage reactance of the windings due to the change in the saturation of the core as I have previously cited. If oscillographic measurements had been made some useful results might have been presented in regard to this point.

His test No. 2 will give correct results only if the resistance is negligibly small as compared with the leakage reactance at fundamental frequency.[3] The advantage of tests Nos. 1 and 2 is that they may be run at normal core saturation. On the other hand potential transformers must be used if the ratio of transformation is other than unity. This is a real disadvantage, inasmuch as their ratio must agree with that of the transformers being tested to within a few hundredths of one per cent in order that they may introduce a small error. The currents also contain large third-harmonic components.

The disadvantages of tests Nos. 3 and 4 are that auxiliary transformers must be used if the ratio of the transformer being tested is other than unity and that the core is run at low saturation, so that if the leakage is a function of the saturation, this factor is disregarded.

The disadvantages of the third-harmonic method are that three identical transformers are required, and that to be certain of the results oscillographic measurements are necessary. On the other hand, the core saturation is normal and no auxiliary transformers are necessary to correct for a ratio other than unity. On the whole it seems to offer the best method for determining the individual leakages.

Let me emphasize, even at the risk of repetition, that the leakage inductance of one winding with respect to another is determined solely by the configuration of the two windings with respect to each other and to the iron core and by the magnetic condition of the latter. This magnetic condition fundamentally depends upon all of the currents acting and upon nothing less.

Now, in regard to three-circuit transformers, I have shown that the reactances which may be used to represent the individual windings in the equivalent net-work that Mr. Boyajian proposes are *not* the leakage reactances of the windings. Equations **6**, **7**, and **8** in my discussion show clearly what their composition really is. For example, the reactance that should be assigned to winding No. 1 is the *leakage* of this winding with respect to winding No. 2 *plus* the differential *mutual* effect of winding No. 3 upon windings Nos. 2 and 1 respectively.

W. V. Lyons

RADIO SETS ON FARMS

The farmers of the United States as a class have become radio enthusiasts and today have more than twice as many radio receiving sets as they did two years ago. In 1923 there were 145,000 receiving sets on farms throughout the country, while at the close of 1925 the number of these farmer sets had risen to 553,000.

Farmers have discovered that in order to get weather and market reports as well as the entertainment they desire they must have "good distance sets," and dealers selling radios to the farmers report that sets worth from $125 to $400 are much easier to sell than sets costing under $100. Also today 24 agricultural colleges in the United States maintain radio broadcasting stations and are paying a great deal of attention to the programs they put on the air.

3. Except when the ratio of resistance to leakage inductance is the same for the two windings.

Starting Characteristics and Control
of Polyphase Squirrel-Cage Induction Motors

BY HORACE M. NORMAN[1]

Associate, A. I. E. E.

Synopsis.—*In the application of squirrel-cage induction motors to such severe service as frequent start and stop or frequent plugging operation, it is desirable to know how much loss the motor will be required to dissipate. Plugging being understood as changing the motor from any speed in one direction to any speed in the opposite direction, by reversing the rotation of the field only.*

The subject of starting loss is also of interest from the control standpoint; such as the application of auto-transformers for starting purposes; or where an external resistance is inserted in the primary as is done in the control of elevator motors.

Consideration is given to the part that the primary and secondary resistance and the total reactance play in the determination and the manipulation of the starting losses; and, as it is true that in many applications the time spent in accelerating the rotor from rest is useless from the production standpoint, consideration is given to the value of secondary resistance that will give minimum starting time for a given field strength. This involves a method for the determination of the time taken to attain a given speed in general.

There are many cases where a motor has already been designed and tested, and is about to be applied on a given job where the cycle of operation is known and includes either starting and stopping or plugging. In such an event, instead of working with the various test values to get the constants of the machine, it is much more convenient and accurate to work from such values as starting torque, maximum torque, slip at full load, locked current and primary resistance.

It will be shown how the proceeding short-cut method can for most cases be made more simple without sacrificing the accuracy of the result to any appreciable extent.

When a motor is plugged the problem is complicated by the difficulty that eddy currents flow in the rotor which give a slight increased effect to the torque at negative speeds. Although this paper does not show how to predetermine its amount, it does show how to handle the losses and the time of reversal, if the test speed-torque values are known or can be estimated from another machine.

* * * * *

WHEN an induction motor is started up in series with an auto-transformer, the ratio of the loss in the motor and auto-transformer at any instant is a constant. The ratio of total loss over the entire starting period must have this same value. As this value can easily be calculated by considering any particular instant, such as the very start, it is obvious that the total loss in the auto-transformer is known when that of the primary of the motor is known. From this it can be seen that the two problems are reduced to that of the motor only.

It is true that in the vast majority of cases the r. m. s. value of starting current is very large compared to the magnetizing current and that sufficient accuracy can be obtained by neglecting the magnetizing current except in so far as it effects the torque.

Reducing the secondary circuit to terms of the primary and neglecting the magnetizing current, the iron, and the friction and windage losses it can be assumed that the secondary current is equal to the primary current. The ratio of the primary loss to the secondary loss during the starting period will then be as their respective resistances. Therefore:

$$\frac{\text{Total primary loss during starting period}}{\text{Total secondary loss during starting period}} = \frac{\text{Primary resistance}}{\text{Secondary resistance}} = \frac{r_1}{r_2}$$

The primary resistance is taken to be per leg of the winding, and the secondary resistance in terms of the primary can be found by

$$r_2 = \frac{T_{st}\, N}{7.04\, \phi\, I_L^2} \qquad (1)$$

where

T_{st} = starting torque
N = synchronous speed in rev. per min.
ϕ = number of phases
I_L = locked amperes per leg

To find the secondary loss during the starting period, it is only necessary to consider the field as at rest instead of the stator. In this case the stator would have to be considered as revolving backwards at synchronous speed and the rotor with it to correspond with the starting condition of the motor: then when the line switch is thrown in, a stationary field is set up which acts as a brake on the revolving rotor and tends to bring it to rest. The only difference between a mechanical and such an electrical brake is that the loss in one is in friction loss and the other in copper loss with perhaps a little iron loss. Since it does not matter to what degree a mechanical brake is applied the total loss is equal to the difference of the kinetic energy before and after, so in this case the loss is proportional to the square of the initial speed less the square of the final speed, the field being considered as stationary, and is also proportional to the total inertia resisting the change of speed. Assuming that there is no friction or hauling load during the starting period, then the rotor loss depends only on the above considerations from which the following formula can be evolved:

$$\text{Rotor loss (Joules)} = .00744\,(M\,I)\,N^2\,(s^2 - S^2) \qquad (2)$$

while changing from speed $N(1 - s)$ to speed $N(1 - S)$, inertia being the only resistance to motion. The total

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Abridgment of paper to be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926. Complete copies available to members on request.

inertia of the whole system being reduced to terms of the rotor and being equal to $(M\ I)$.

From this it can be seen that the loss during plugging is about four times as great as that for starting only.

Further, since the primary loss is to the secondary loss as r_1 is to r_2, and since the secondary loss is independent of the value of the secondary resistance, then it follows that the higher the secondary resistance the lower will be the primary loss during the starting or reversing period.

Assuming that the primary resistance varies as the turns squared, which is probable, then it is true that neither the primary nor secondary total joules loss during the starting period can be raised or lowered by changing the number of primary turns.

This is obvious when it is considered that the secondary resistance in terms of the primary varies as the primary turns squared; that is, as the primary resistance. The ratio of resistances is therefore a constant, and since the losses are of the same ratio and remembering that the secondary starting loss is independent of the secondary resistance, then the primary starting loss in joules is independent of the primary turns, assuming that the resistance varies as the turns squared.

It is also obvious that changing the primary voltage will not change these starting losses.

Any increase or decrease in reactance due to change of saturation or variation of turns does not change the total joules loss at start, it merely increases or decreases the time of start.

These arguments neglect friction and windage of the accelerated system which as a rule are of only secondary consideration.

It is, therefore, clear that the only way to decrease the starting loss of a squirrel-cage induction motor is to increase the secondary resistance. This, however, cannot be brought to the extreme because, if enough resistance be added, the accelerating torques will be reduced so much that the time taken to attain a given speed would be excessive and further the full-load slip would be too great, giving a very low running speed and poor efficiency.

The question then arises: What is the value of secondary resistance to best suit a given application?

There are two factors that enter into the determination of the answer. First, is the secondary resistance to be such that the losses in the motor during a complete cycle of operation are to be a minimum; and second, is it desirable to start up in the minimum time.

It is obvious that no mathematics can decide what compromise should be made between the two values of secondary resistance obtained from the two above considerations; but even though neither ideal is finally selected it is well to know what they are, so that the secondary resistance can be made some intermediate value.

To find the total losses during a complete cycle of operation, it is only necessary to multiply the running losses by their duration in seconds and add the starting or plugging loss in joules. This gives the total joules loss over a complete cycle of operation and if divided by the total time for the complete cycle, it gives the average watts loss for continuous operation.

The value of secondary resistance to give minimum average loss for continuous operation will naturally depend on the time and variation of the load and the number of stops and starts or reversals.

Assuming that the torque T for any slip s is given by

$$T = \frac{7.04\ E^2\ r_2\ \phi\ s}{N\left[r_2^2\left(\frac{E}{E_g}\right)^2 + 2\ r_1\ r_2\ s + (r_1^2 + x^2)\left(\frac{E}{E_g}\right)s^2\right]} \quad (3)$$

then the time taken to start from rest and reach a speed corresponding to a slip of S is given by

$$\text{Time (seconds)} = .01487\ \frac{(M\ I)\ N}{E^2\ \phi}$$

$$\left[r_2\left(\frac{E}{E_g}\right)^2 \log_e\left(\frac{1}{S}\right) + 2\ r_1\ (1 - s)\right.$$

$$\left. + \left(\frac{E}{E_g}\right)\frac{(r_1^2 + X^2)\ (1 - S^2)}{2\ r_2}\right] \quad (4)$$

Where

$(M\ I)$ = moment of inertia of the whole system transferred to and including the rotor (lb-ft.).

N = synchronous speed (rev. per min.)

E = Primary volts per leg

E_g = $E - X_1\ I_m$

$X_1\ I_m$ = no-load reactance drop in primary

ϕ = number of phases

r_1 = primary resistance per leg (add external primary resistance if any)

r_2 = secondary resistance per leg in turns of primary

X = total reactance (add external primary reactance if any)

S = normal or final slip

Use .0149 for constant

Assuming that all the constants of the motor are fixed with the exception of the secondary resistance, then the value of secondary resistance to give minimum time to attain a given speed can be derived from the preceding equation and will be as follows:

$$r_2 = \sqrt{\frac{(X^2 + r_1^2)\ (1 - S^2)}{4.6\left(\frac{E}{E_g}\right)\log_{10}\left(\frac{1}{S}\right)}} \quad (5)$$

This formula gives the value of r_2 which would speed the motor from rest to $N\ (1 - S)$ revolutions per minute in the least time.

Oscillograph records were taken of a squirrel-cage motor when starting up and when plugged in order to check the assumption that the dry bearings at start cause a delay which is small compared with the total time of start; they were also taken with a view to checking the time to establish the field.

Fig. 1A and B show the current in the primary building up when the motor is started and plugged. It can be seen from A that the current is normal after

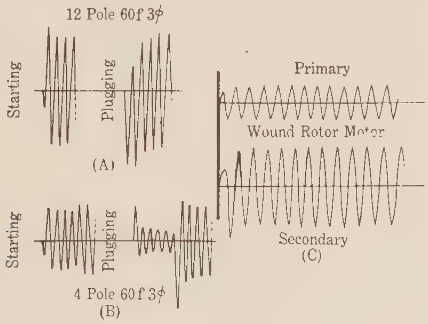

FIG. 1

about two cycles when the motor is started from rest and after four cycles when plugged. From B it can be seen that for start the current has about 90 per cent of its full value for about four cycles, and is then normal; when plugged there is some irregularity but after seven cycles the current is stable. This irregularity is probably due to one of the poles of the switch making bad

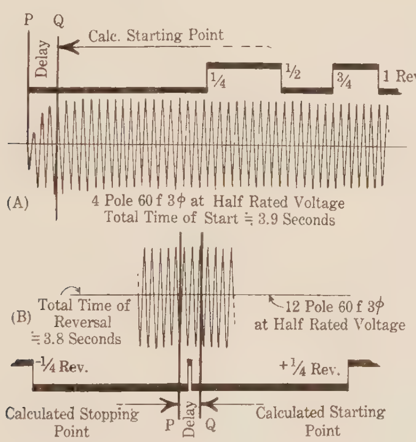

FIG. 2—(A) FOUR-POLE, 60-CYCLE, AT HALF RATED VOLTAGE, TOTAL TIME OF START = 3.9 SEC. (B) TWELVE-POLE, 60-CYCLE, AT HALF-RATED VOLTAGE, TOTAL TIME OF REVERSAL = 3.8 SEC.

contact. Later tests with a wound rotor showed that one of the contacts was poor as the primary current in this particular phase did not start till about one-tenth of a second after the secondary current had started up. This indicates that a faulty switch can cause excess loss in the motor because as soon as two poles make contact the motor will draw single-phase current which causes a loss in the stator and rotor but gives zero torque. It is only when the third pole makes contact that the motor starts up.

Fig. 1C shows the primary and secondary current of a wound rotor motor when started from rest. It can be seen that the secondary current builds up inside of two cycles.

From these tests it can be seen that it is not unreasonable to neglect the time taken to establish the field and the secondary current.

Fig. 2A shows the primary current waves of a squirrel-cage motor when starting up; and above it a line which is displaced after the rotor turns one quarter of a revolution and remains so for the next quarter revolution, etc. This line is obtained by mounting two contact strips diametrically opposite to each other on a paper pulley, each covering one quarter of the circumference of the pulley.

The pulley is mounted on the motor shaft so that every time a contact piece passes a stationary carbon brush a current is established which actuates the oscillograph. Working back from slips of 10 per cent, 50 per cent and 75 per cent to get the moment of inertia

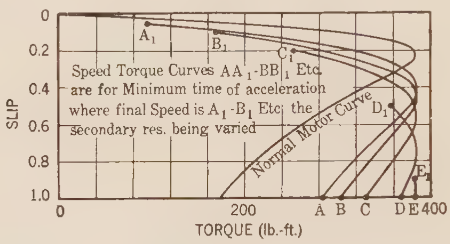

FIG. 3—SPEED TORQUE CURVES

A A-B B etc., are for min. time of accelerations where final speed is *A*, *B* etc., the final secondary resistance being varied

of the rotor and pulley and then using the result to get the instant of start, assuming there is no delay, the point Q is reached. Since the switch was thrown in at the instant P then the difference represents the delay. Fig. 2B represents the same thing when the motor is plugged. The delay in this case is for the excess friction when the rotor is changing direction of rotation. Both these delays are very small compared with the total time of start or plugging.

The usual value of friction and windage for a motor is such that it lowers the efficiency by only a few per cent so that it has the effect of reducing the torque exerted by the field on the rotor by only a few per cent at full load. For greater values of slip this reduction is less while the field torque is greater, which shows that it is justifiable to neglect it during the accelerating period, which has been done in the previous formulas.

Fig. 3 shows a series of curves each having the same maximum torque value, but which are for different values of secondary resistance. The various starting torques are obtained by using the value of secondary resistance obtained by formula (**5**) when the slips corresponding to A_1 B_1 etc., are used. These curves then give an idea of what shape the speed torque curve should have for the minimum time of acceleration to a

given speed (assuming that the only resistance to motion is in the form of inertia).

It should be noted that an erroneous conception is often held that the time of acceleration varies inversely as the average torque.

This would lead to the conclusion that a single-phase motor would start up since it has a definite average torque. The fact is that the time for any constant value of torque varies inversely as this torque, and this can be applied with reasonable accuracy for small changes in slip, but for the total accelerating period, it should be noted that the time of acceleration varies as the average of the inverse of the torque. This average being obtained by taking the inverse of the torques for equal increments of speed. From this it can be seen that the time can be abnormal if the torque for any speed whatever approaches zero and would be infinite if it did drop to zero, which means that the motor would never speed up beyond this point.

It is sometimes assumed that if the value of locked

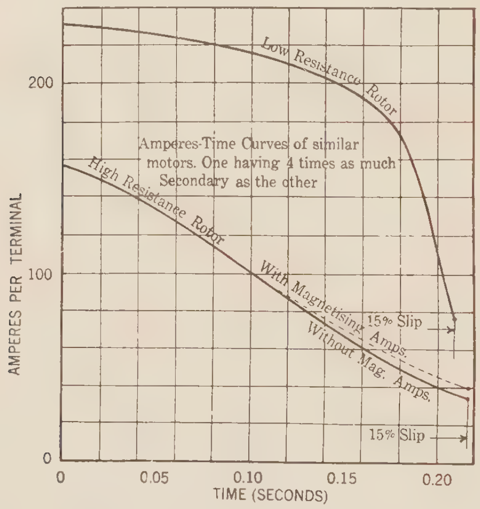

FIG. 4—AMPERE-TIME CURVES OF SIMILAR MOTORS

One having four times as much secondary resistance as the other

amperes is used for zero time and full-load amperes for the end of the accelerating period, then the current curve could be assumed to be a straight line joining these two points. This is not necessarily true, but happens that for some high resistance rotor motors it is nearly so. However, it is far from true of the average motor where the starting current tends to hang on, and in Fig. 4 is shown to be as high as 93 per cent of locked value after half the starting time is passed. This is the upper curve for the low resistance rotor. The lower curve is for a rotor with four times as much resistance, and it can be seen that the current falls off nearly as a straight line.

The torque curve for this latter motor would have nearly maximum torque at start.

It will be noted from these two curves how much the starting current is reduced for the high resistance rotor compared with the normal rotor, and also that the average current is still a lower ratio. The root mean square value of the two curves should have a ratio of nearly two because the time of start for each case is practically the same. The r. m. s. value of each current curve when multiplied by the time of start should have a ratio of exactly two, which, when squared and multiplied by the ratio of resistances gives unity; showing that the rotor loss is the same in either case as previously shown.

Since the stator winding is the same for either case, and noting that there is little difference in the time of start, it can readily be seen that the stator loss is much lower for the high resistance rotor than for the normal rotor.

TIME OF ACCELERATION USING TEST VALUES OF TORQUES

Taking the case of a normal resistance rotor motor when the duty cycle is known, it is true that in the majority of cases the motor which is finally selected has already been built and tested.

In such a case it is quicker to use these tested torques, than if a complete calculation were made of the machine.

The values required to find the time of acceleration from rest to a given speed are the slip at load torque equal to the starting torque, the maximum and starting torques, synchronous speed and moment of inertia of the rotor if starting light, and if loaded then the equivalent moment of inertia of the whole system, reduced to terms of the rotor.

Let

Maximum torque	$= T_m$
Starting torque	$= T_{st}$
Slip at load torque equal to T_{st}	$= s_1$
Synchronous speed	$= N$
Moment of Inertia (total)	$= (M\,I)$

$$T = \frac{a\,s}{b + c\,s + s^2} \qquad (4)$$

[Refer to formula (3)] where a, b and c are constants.

(a) $a = T_{st}\,(b + c + 1)$

(b) $b = s_1$

(c) $c = \dfrac{T_{st}\,(1 + s_1) - 2\sqrt{s_1}\,T_m}{T_m - T_{st}}$

From (a) (b) (c) the values of a, b and c can be found and can be substituted in a corresponding formula to (4), as follows:

Time of acceleration (sec.)

$$= \frac{\pi\,(MI)\,N}{30\,a}\left[2.3\,b\log_{10}\left(\frac{1}{S}\right) + c(1-S) + \frac{1-S^2}{2}\right] \qquad (6)$$

from rest to slip of S.

When the speed reaches 90 per cent to 95 per cent of synchronous speed, it can be assumed that it is near enough to be counted up to speed; then if 90 per cent is taken the log to the base ten becomes unity and for 95 per cent it becomes 1.301. It makes only a slight

difference in the time of start, whichever of the above final speeds is chosen.

Approximate Method Using only Maximum and Starting Torques

The preceding method can be simplified by assuming that the torque curve has a formula:

$$T = \frac{a\,s}{b + s^2} \tag{8}$$

It should be noted that the value of a and b will be different in this formula than in formula (**6**) so that the part c plays is not entirely neglected.

Using only the maximum and starting torques, the value of a and b for this formula are found in the following:

$$a = 2\,S_m\,T_m \text{ or } = T_{st}\,(1 + b)$$
$$b = S_m^2$$

where

$$S_m = \left(\frac{T_m}{T_{st}}\right) - \sqrt{\left(\frac{T_m}{T_{st}}\right)^2 - 1} = \text{Slip at maxi-}$$

mum torque as given by formula (**8**)

The curve plotted by using these values of a and b will have the same maximum and starting torque as test curve and will follow the test curve very closely.

The time equation then becomes:

$$\text{Time (seconds)} = \frac{\pi}{30} \times \frac{(M\;I)\;N}{a}$$
$$\left[2.3\,b\log_{10}\left(\frac{1}{S}\right) + \frac{1 - S^2}{2}\right] \tag{9}$$

Fig. 5 shows a test speed torque curve and the calculated values for formula (**6**) plotted as (o) and those for formula (**8**) plotted as (x).

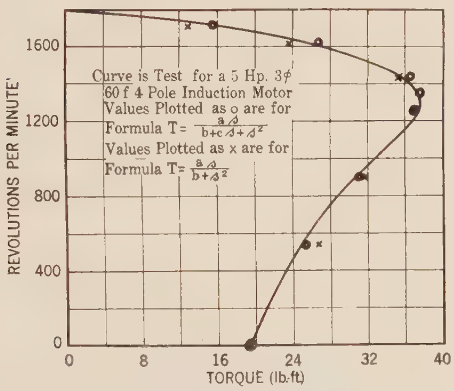

Fig. 5—Test Curve for 5-h. p., Three-Phase, 60-Cycle, Four-Pole, Induction Motor

Values plotted as O are for formula

$$T = \frac{a\,S}{b - c\,S - S^2}$$

Values plotted as X are for formula

$$T = \frac{a\,S}{b - S^2}$$

Speed Torque Equation for High-Resistance Rotor Motors

The two previous methods cannot be used for finding the equation of the speed torque curve of a motor which has approximately maximum torque 'at start. The following method should be employed: Find the ratio of torque to slip for a point infinitely close to the point torque = o, slip = o, by drawing a tangent to the curve at this point. Let this value be tangent θ.

Take the slip for some load torque, preferably of two-thirds the value of the starting torque. Let this slip be S_1 and the torque T_1. Let the starting torque $= T_{st}$

Then

$$a = b\tan\theta$$

$$b = \frac{1}{\dfrac{1}{S_1} - \dfrac{(T_{st} - T_1)\tan\theta}{(1 - S_1)\,T_{st}\,T_1}}$$

$$b = \frac{1}{\dfrac{1}{S_1} - \dfrac{\tan\theta}{2\,(1 - S_1)\,T_{st}}} \quad \text{if } T_1 = \frac{2}{3}T_{st} \tag{10}$$

$$c = \frac{a}{T_{st}} - b - 1$$

and

$$\text{Torque} = T = \frac{a\,s}{b + c\,s + s^2}$$

Fig. 6 shows the test speed-torque curve in full,

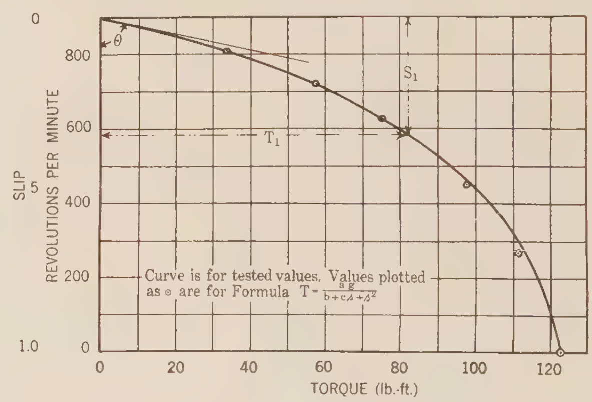

Fig. 6—Curve for Tested Values

Values plotted as O are for formula

$$T = \frac{a\,S}{b - c\,S - S^2}$$

and points calculated by this method plotted as (⊙).

Plugging Service

When a motor is plugged there are eddy currents in the rotor which are very pronounced at negative speeds. These eddy currents cause an increase in the rotor loss over what it would be if measures were taken to prevent eddy currents. This increase in the rotor loss makes the torque larger and since the eddy currents increase as the

slip increases it follows that the torques are affected more at negative speeds than at positive speeds. The increase in torque can be considerable and makes quite a difference in time of deceleration, and also in the joules loss in the primary.

When it is stated that there are eddy currents in the rotor it is meant that there are additional currents in the rotor bars besides a uniformly distributed current. These additional currents add in some places and subtract in others from the uniformly distributed current, and have the resultant effect of an uneven distribution.

Since the rotor copper loss is proportional to the average of the density squared of the current, then it can be shown that this loss is least when the density is uniform over the rotor bar. The loss must, therefore, be greater when the distribution is uneven, and this condition can be duplicated by a higher resistance rotor having no eddy currents.

The uneven distribution of current in the rotor bar is caused by variation of leakage flux linkages for different sections of the rotor bars, and is therefore more and more pronounced the higher the rotor frequency.

It is true that near standstill there is not a great deal of excess torque over what would be expected so that the equivalent secondary resistance can be assumed to be constant between rest and synchronous speed.

Since the derivation of formula (**2**) shows the secondary loss to be independent of the value of secondary resistance during acceleration or retardation, then it follows that it will be independent of a varying value of secondary resistance. But even though the primary resistance is constant the primary loss during this period depends on the variation of the secondary resistance.

For a high-resistance rotor motor, the major loss is in the secondary copper so that any variation in the primary loss as found by formula (**2**) when multiplied by the ratio of resistances can be neglected. Besides this latter consideration, it should be noted that a high resistance rotor will have less eddy currents than a low resistance rotor.

Therefore, when a high-resistance rotor motor is plugged the total loss during the total plugging time can be found by the following:

Joules loss in stator and rotor

$$= 0.00744 \frac{r_1 + r_2}{r_2} (M\,I)\,N^2\,(4 - S^2) \qquad \textbf{(11)}$$

For high resistance rotor motors only and when motor is plugged.

When a low resistance rotor motor is plugged the primary loss is much less than the above formula would assume. The main difference being while the rotor is decelerating. The primary loss in joules during this time can be approximately found by assuming that the current is of constant value and equal to the current at the instant of plugging. This is very nearly true of a low resistance rotor motor but not so of a high resistance rotor motor in which case this current may be 30 per cent greater than the locked amperes.

The joules loss can be found by the following formula.

Joules loss in stator and rotor

$$= 0.00744 (M I) N^2 \left[\frac{r_1}{r_2} (1 - S^2) + 4 - S^2 \right] + \phi r_1 I_p^2 t_p \quad \textbf{(12)}$$

For low resistance rotor motors only and when rotor is plugged.

Where

I_p = amperes per leg of the winding at the instant of plugging.

and

t_p = time for rotor to come to rest.

The value of t_p can be approximately found as follows:

$$t_p \text{ (seconds)} = \frac{\pi}{60} (M\,I)\,N \frac{T_{plug} + T_{st}}{T_{plug} \times T_{st}}$$

where

T_{plug} = the torque at the instant of plugging.

Equivalent Moment of Inertia (In Terms of the Rotor)

It will be noticed that every time and loss formula includes the term $(M\,I)$ which is the total inertia of the whole system reduced to terms of the rotor.

As this figure is the result of multiplying every small mass by its velocity squared and comparing it with that of the rotor, it can be seen that there are many cases where the rotor, due to its high speed, plays the major part in holding back the whole system from instantly coming up to speed.

The moment of inertia of the rotor should be known then if the preceding formulas are expected to give the correct losses and times.

The following method lends itself to great accuracy, due to the fact that the only measurement necessary is time. The other dimensions used are the journal sizes, which are very accurately ground to size, and are both of equal size and known beforehand.

The equipment is two rails accurately machined to a very large radius. These are placed parallel to each other and the rotor is placed on them so that each journal rides on a rail.

As the rails are circular the rotor naturally will swing back and forth with a harmonic motion.

Fig. 7 shows the scheme suggested.

Let

R = radius of gyration of the rotor (ft.)

P = period of rotor swing (sec.)

r = radius of rotor bearings (ft.)

l = radius of the circular rails (ft.)

g = gravity

Then

$$\text{Radius of gyration} = R = r \sqrt{\frac{P^2\,g\,(l - r)}{4\,\pi^2\,l^2} - 1}$$

When this formula is used it will be noticed that the

first term under the radical is very large compared with the second term, provided that l is very large. The accuracy with which R is obtained then approaches that of the period P.

The radius of the rails l should be made very large so that the period becomes very large and tends to eliminate windage, and also so that for a given amplitude of swing the angle of the rails will be small and so prevent slipping of the journals on the rails.

The accuracy of R is unaffected by the fact that the rotor might be placed on the rails slightly skewed so that when at rest the bearings would not be at the lowest point of the rails.

External Moving Parts

In transferring the inertia of external moving parts to terms of the rotor, the following rules are sufficient for most cases.

1. All parts that have only linear motion should be transferred according to the following law.

$$(M\ I) \text{ equivalent} = \frac{W}{g}\left(\frac{30\ V}{\pi\ (\text{r. p. m.})}\right)^2$$

Where

$(M\ I)$ equivalent = moment of inertia when

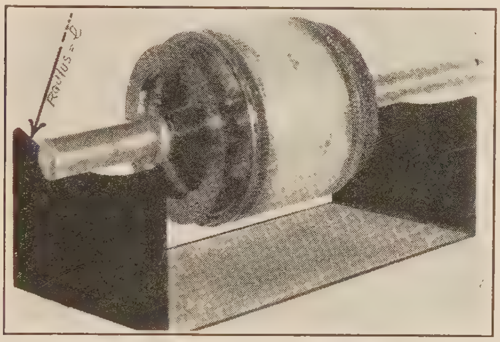

Fig. 7—Curve for Tested Valves

Valves plotted O are for formula

$$T - \frac{a\ S}{b - c\ S - S}$$

transferred to the rotor.

W = external weight in lb.

V = velocity of W in ft. per sec.

g = gravity

(r. p. m.) = revolutions per min. of rotor

2. All parts that have a rotary motion only should be transferred by having their moment of inertia multiplied by the square of the ratio of their speed compared with the speed of the rotor.

All previous formulas pertaining to loss or time have been evolved with the assumption that the only resistance to motion is inertia. This is approximately so in a great many cases, but if any particular application should have a large friction or hauling load to overcome then these formula cannot be used. Any friction or hauling load should be applied as a reduction in torque and not as some supposedly equivalent inertia.

If the complete current torque curve be not available then it can be built up from the speed-torque curve by the following:

$$I_1 = I_2 = \sqrt{\frac{N\ s\ T}{7.04\ \phi\ r_2}} = \sqrt{s\ T} \times \text{constant}$$

where s and T are the values of slip and torque corresponding to the current.

Conclusion

For all cases worked out the primary loss has been found so that if some type of control be in the circuit, the loss can be found for it during a complete cycle of operation. The proper size controller can then be applied which will not have an excessive factor of safety.

When a motor is to be used for either starting and stopping or reversing service, the total losses of the motor during a complete cycle can be found by the preceding formulas. Knowing from test the amount of loss that the motor can dissipate for a definite rise of temperature, and knowing the loss it will be required to dissipate, the temperature rise of the motor can be predicted.

This estimated rise indicates whether or not the proper size motor has been selected.

THE DISTANCE RANGE OF RADIO TELEPHONE BROADCASTING STATIONS

As is well known, the conditions affecting radio transmission are too complex to permit a simple analysis. A direct method of studying such conditions and their variations is the analysis of a large number of similar observations taken by an organized group of observers of receiving conditions. The Bureau of Standards has made such an investigation, and part of the results are described in a paper just issued, Technologic Paper No. 297, A Statistical Study of Conditions Affecting the Distance Range of Radio Telephone Broadcasting Stations, by C. M. Jansky, Jr. This paper describes one year's work on the investigation of conditions affecting distance range of broadcasting stations by the Bureau of Standards with the aid of about 100 voluntary observers. The observations were made for a year in the period 1922-23 on transmitting station KDKA of the Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa. The observers were scattered over all distances up to 400 miles from the transmitting station. The data obtained were analyzed on automatic machines. The paper gives charts showing (1) variation of strength of atmospherics, (2) variation of fading, (3) relative magnitude of obstacles to reception, (4) variation of interference from receiving sets, (5) relative magnitude of obstacles to reception grouped in bimonthly periods, and (6) mean reliability of reception as a function of distance. A copy of this paper may be obtained for 5 cents from the Superintendent of Documents, Government Printing Office, Washington, D. C.

The Cross-Field Theory of Alternating-Current Machines

BY H. R. WEST[1]

Associate, A. I. E. E.

***Synopsis.**—It is the purpose of this paper to show how analysis by the cross-field theory may be used to obtain accurate, purely numerical methods of calculating performance characteristics of alternating-current machines. Methods of calculation are derived and sample calculations are given for the single-phase induction motor and the repulsion motor.*

ALTERNATING-current machines may be analyzed according to either the revolving-field or the cross-field theory. Each of these theories has its own individual merits, depending more or less on the type of machine under consideration. Some phenomena are more easily understood by a study following the revolving-field theory, and other phenomena are made more clear by use of the cross-field theory.

For routine calculation of performance characteristics of alternating-current machines, many graphical and analytical methods have been developed. These different methods also have their own individual merits and the choice of a method of calculation should depend partly on what is most desired; *e. g.*, speed, accuracy, or aid to visualization.

Therefore, we may say that, in general, neither the revolving-field nor the cross-field method of analysis, and no one method of calculation, graphical or analytical, should be used exclusively. Although this paper deals only with a general analytical method of studying some types of a-c. machines using the cross-field theory, it is not by any means intended as a plea for the exclusive use of this general method, for it is recognized that whatever usefulness it may have will be found in rather limited fields.

In the following, the attempt is made to show how a general method of analysis, following the cross-field theory, may be applied to alternating-current motors to obtain simple and accurate, purely numerical methods for routine calculations of performance characteristics. The fundamental principles of the analysis of motors by the cross-field method are, of course, very well known. The general method given below is fundamentally the same as that outlined by Steinmetz in his "Theory and Calculation of Electrical Apparatus," but differs from it in the treatment of the leakage reactance, and in the arrangement of the results.

Briefly stated, the general method as applied to a motor is as follows: Kirchoff's voltage equations are set up for the different circuits of the motor and are solved to obtain equations for the currents in each of the circuits in terms of the applied voltage, the design constants of the motor and the speed. From these equations, other equations for the fluxes linking or cut by the rotor conductors are obtained. The torque corresponding to any one of the rotor circuits is obtained by multiplying the in-phase components of the current and the fluxes cut by the conductors of that circuit. Adding the components of torque corresponding to each of the rotor circuits, we obtain an expression for the total torque developed, which, multiplied by the speed, gives the power generated. Subtracting from this the friction losses gives the power output. The power input is, of course, given by the product of the applied voltage and the in-phase component of the line current.

In this paper, the angle of hysteretic lag between flux and m. m. f. is neglected in the analytical solutions, and correction for core loss is made in the numerical calculations by treating the core loss the same as if it were a friction loss. If it should be desirable, the angle of hysteretic lag can be taken into account by using the complex quantity $Z_m = R_m + j\,X_m$ for the magnetizing impedance in place of the pure reactance $j\,X_m$ which is used in the equations in the following part of this paper. This would complicate matters slightly by adding to the lengths of the equations, and would yield but a very slight increase in accuracy. In almost all cases, the slight increase in accuracy would not justify the extra labor and chances for numerical errors.

Sine wave distributions of m. m. f., and uniform air-gap permeance are assumed in all cases.

The details and application of the method can best be shown by means of examples, as follows:

The Single-Phase Induction Motor

According to the cross-field theory, the components of the main flux of the motor and the rotor currents are considered separately in two axes at right angles to each other. The axis of the stator winding may be called the transformer axis, and the axis at right angles to it the field axis. A squirrel cage is considered as equivalent to a commutated winding with brushes bearing on the commutator short circuited on themselves in the transformer and field axes. The motor can then be represented diagrammatically as in Fig. 1.

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The following symbols will apply:

E = applied voltage
I_1 = line current
I_{1a} = power component of line current
I_{1b} = reactive component of line current
I_{2t} = rotor current in the transformer axis
I_{2f} = rotor current in the field axis
r_1 = resistance of the stator winding
r_2 = resistance of each of the rotor circuits
X_m = mutual inductive reactance of the stator and rotor windings
x_1 = leakage reactance of the stator winding
x_2 = leakage reactance of each of the rotor circuits
N = effective number of turns in each of the circuits
f = frequency of applied voltage
S = speed as a fraction of synchronism

The symbols for voltage and current all represent r. m. s. values of time vector quantities. The positive senses of the currents are indicated by the arrows in Fig. 2.

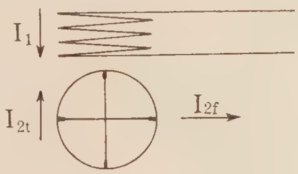
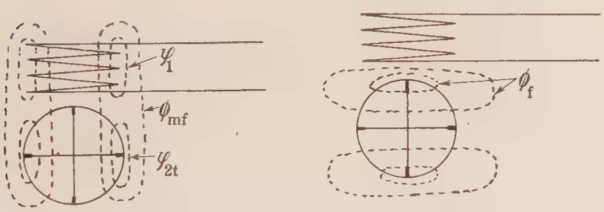


Fig. 1

The motor flux is resolved into the following four components: (1) the "transformer" flux Φ_{mt} which is the flux that is mutual to the stator winding and the rotor circuit in the transformer axis; (2) the "field flux Φ_f which is the flux produced by the m. m. f. of the current I_{2f} in the field axis of the rotor; (3) the leakage flux φ_1 of the primary, and (4) the leakage flux φ_{2t} of the rotor circuit in the transformer axis.



A B

Fig. 2—Flux Component in Single-Phase Induction Motor

(a) In transformer axis
(b) In field axis

In terms of the currents and the motor reactances, the equations for the above flux components are:

$$\Phi_{mt} = \frac{X_m (I_1 - I_{2t})}{2 \pi f N} \tag{1}$$

$$\Phi_f = \frac{(X_m + x_2) I_{2f}}{2 \pi f N} \tag{2}$$

$$\varphi_1 = \frac{x_1 I_1}{2 \pi f N} \tag{3}$$

$$\varphi_{2t} = \frac{x_2 I_{2t}}{2 \pi f N} \tag{4}$$

Voltage applied to the stator terminals must overcome the resistance drop and the mutual and leakage reactance drops due to alternation of Φ_{mt} and φ_1. The equation is

$$E = r_1 I_1 + j x_1 I_1 + j X_m (I_1 - I_{2t}) \tag{5}$$

In the transformer axis of the rotor, the sum of the voltages induced by transformer action of Φ_{mt} and φ_{2t}, and by rotation through the flux φ_f plus the resistance drop $r_2 I_{2t}$ must equal zero. The equation is, for counter clockwise rotation of the rotor,

$$0 = -j X_m (I_1 - I_{2t}) - S (X_m + x_2) I_{2f} + r_2 I_{2t} + j x_2 I_{2t} \tag{6}$$

Similarly for the field axis of the rotor,

$$0 = j (X_m + x_2) I_{2f} - S X_m (I_1 - I_{2t}) + S x_2 I_{2t} + r_2 I_{2f} \tag{7}$$

Solving these three voltage equations for I_1, I_{2t}, and I_{2f} we get,

$$I_1 = E \frac{[-r_2^2 + (1 - S^2)(X_m + x_2)^2 - j\, 2 r_2 (X_m + x_2)]}{U_1' + j W_1'} \tag{8}$$

$$I_{2t} = E X_m \frac{(1 - S^2)(X_m + x_2) - j r_2}{U_1' + j W_1'} \tag{9}$$

$$I_{2f} = - \frac{S E X_m r_2}{U_1' + j W_1'} \tag{10}$$

Where

$$U_1' = - r_1 r_2^2 + 2 r_2 x_1 (X_m + x_2) + r_2 X_m (X_m + 2 x_2) + (1 - S^2) r_1 (X_m + x_2)^2 \tag{11}$$

$$W_1' = - r_2^2 x_1 - 2 r_1 r_2 (X_m + x_2) - r_2^2 X_m + (1 - S^2) [x_1 (X_m + x_2)^2 + x_2 X_m (X_m + x_2)] \tag{12}$$

Substituting the above values of I_1, I_{2t}, and I_{2f} in equations (1), (2) and (4), we get

$$\Phi_{mt} + \varphi_{2t} = \frac{- E X_m [r_2^2 + j r_2 (X_m + x_2)]}{2 \pi f N (U_1' + j W_1')} \tag{13}$$

and

$$\Phi_f = - \frac{S E X_m (X_m + x_2) r_2}{2 \pi f N (U_1' + j W_1')} \tag{14}$$

The torque developed by the motor consists of two components, one component T_1 due to the interaction of the current I_{2t} and the flux Φ_f, and another component T_2 due to the interaction of I_{2f} and the flux $\Phi_t = \Phi_{mt} - \varphi_{2t}$. These torque components in synchronous watts are equal to the products of the in-phase components of the currents and the fluxes with which they interact multiplied by $2 \pi f N$; that is, from equations (9) and (14).

$$T_1 = \frac{E^2 X_m^2 (X + x_2)^2 r_2 S (1 - S^2)}{U_1'^2 + W_1'^2} \tag{15}$$

and from equations (10) and (13)

$$T_2 = \frac{-E^2 X_m^2 r_2^3 S}{U_1^{1\,2} + W_1^{1\,2}} \tag{16}$$

and the total torque developed by the motor is

$$T = T_1 + T_2 = \frac{E^2 X_m^2 r_2 S [(1 - S^2)(X_m + x_2)^2 - r_2^2]}{U_1^{1\,2} + W_1^{1\,2}} \tag{17}$$

This equation shows that the torque developed by the motor is zero when

$$1 - S^2 = \frac{r_2^2}{(X_m + x_2)^2}$$

or the ideal no-load speed is

$$S_0 = \sqrt{1 - \frac{r_2^2}{(X_m + x_2)^2}} \tag{18}$$

Substituting the above value for the no-load speed in equation (7), we obtain for the no-load current,

$$I_0 = \frac{2E(X_m + x_2)}{2r_1(X_m + x_2) + \dfrac{r_2 X_m^2}{X_m + x_2} + jX_m[X_m + 2(x_1 + x_2)]}$$

For all usual relative values of the design constants, this is very closely,

$$I_0 \cong -j\frac{2E}{X_m}\left[\frac{X_m + x_2}{X_m + 2(x_1 + x_2)}\right]$$

$$\cong -j\frac{2E}{X_m}\left[1 - \frac{2x_1 + x_2}{X_m + 2(x_1 + x_2)}\right] \tag{19}$$

It is obvious that by means of this equation, the value of the magnetizing reactance X_m can be calculated with any desired degree of accuracy from the values of the short-circuit and no-load currents.

The performance characteristics of a motor of given design constants can be calculated completely by means of equations (8) and (17). The solution of these equations can be reduced to a simple matter of arithmetic by means of a suitable printed form, arranged for carrying out the calculations for a number of different speeds simultaneously. The use of very large numbers will be avoided and the calculations for motors of different sizes will be more nearly alike if the numerators and denominators are divided by $(X_m + x_2)^2$ and $(X_m + x_2)^4$ in equations (8) and (17) respectively. This gives

$$I_1 = \frac{M_1 + jN_1}{U_1 + jW_1} \tag{8'}$$

$$T = \frac{SF_8 + S(1 - S^2)F_9}{U_1^2 + W_1^2} \tag{17'}$$

Where

$M_1 = F_1 + (1 - S^2)F_2$
$N_1 = F_3$
$U_1 = F_4 + (1 - S^2)F_5$
$W_1 = F_6 + (1 - S^2)F_7$

The complete expressions for F_1 to F_9 inclusive are given in the following sample calculation.

Performance Calculation of Single-Phase Induction Motor

Motor design constants:

$E = 220$
$r_1 = 0.12$
$r_2 = 0.3$
$x_1 = 0.4$
$x_2 = 0.4$
$X_m = 15$

Core loss and friction = 600

$$F_1 = -E\frac{r_2^2}{(X_m + x_2)^2} = -0.0835$$

$$F_2 = E = 220$$

$$F_3 = -2E\frac{r_2}{X_m + x_2} = -8.57$$

$$F_4 = r_2\left[\frac{x_2 X_m - r_1 r_2}{(X_m + x_2)^2} + \frac{X_m + 2x_1}{X_m + x_2}\right] = 0.315$$

$$F_5 = r_1 = 0.12$$

$$F_6 = -r_2\left[\frac{r_2(X_m + x_1)}{(X_m + x_2)^2} + \frac{2r_1}{X_m + x_2}\right] = -0.0105$$

$$F_7 = x_1 + x_2\frac{X_m}{X_m + x_2} = 0.789$$

$$F_8 = -E^2 r_2^3\frac{X_m^2}{(X_m + x_2)^4} = -5.23$$

$$F_9 = E^2 r_2\frac{X_m^2}{(X_m + x_2)^2} = 13{,}800.$$

	S	1.00	0.98	0.95	0.90	0.80
	$1 - S^2$	0	0.0396	0.0975	0.19	0.36
	$S(1 - S^2)$	0	0.0388	0.0927	0.171	0.288
(1)	F_1	−0.0835	−.08	−0.08	−.08	−0.08
(2)	$(1 - S^2) F_2$	0	8.70	21.4	41.7	79.2
(3)	$M_1 = (1) + (2)$	−0.0835	8.62	21.3	41.6	79.1
(4)	$N_1 = F$	−8.57	−8.57	−8.57	−8.57	−8.57
(5)	F_4	0.315	0.315	0.315	0.315	0.315
(6)	$(1 - S^2) F_5$	0	0.005	0.012	0.023	0.043
(7)	$U_1 = (5) + (6)$	0.315	0.320	0.327	0.338	0.358
(8)	F_6	−0.0105	−0.010	−0.010	−0.010	−0.010
(9)	$(1 - S^2) F_7$	0	0.031	0.077	0.150	0.284
(10)	$W_1 = (8) + (9)$	−0.0105	0.021	0.067	0.140	0.274
(11)	$M_1 U_1$	−0.0263	2.76	6.98	14.05	28.3
(12)	$N_1 W_1$	0.09	−0.18	−0.57	−1.20	−2.35
(13)	$M_1 U_1 + N_1 W_1$	0.0637	2.58	6.41	12.85	25.95
(14)	$N_1 U_1$	−2.70	−2.74	−2.80	−2.90	−3.06
(15)	$- M_1 W_1$	−0.0009	−0.181	−1.43	−5.82	−21.66
(16)	$N_1 U_1 - M_1 W_1$	−2.70	−2.92	−4.23	−8.72	−24.72
(17)	U_1^2	0.0992	0.1025	0.107	.1143	0.1282
(18)	W_1^2	0.0001	0.0004	0.0045	.0196	0.0751
(19)	$U_1^2 + W_1^2$	0.0993	0.1029	0.1115	.1339	0.2033
(20)	$I_{1a} = (13)/(19)$	0.642	25.1	57.5	95.8	127.5
(21)	$I_{1b} = (16)/(19)$	−27.2	−28.4	−38.0	65.2	121.5
(22)	$I_1 = \sqrt{I_{1a}^2 + I_{1b}^2}$	27.3	38.0	69.4	116	176
(23)	Power factor = (20)/(22)		0.66	0.83	0.825	0.725
(24)	Power input = E . (20)		5510	12660	21100	28000
(25)	$S F_8$	−5.23	−5.1	−5	−5	−4
(26)	$S (1 - S^2) F_9$	0	535	1280	2360	3970
(27)	(25) + (26)	−5.23	530	1275	2355	3966
(28)	T = (27)/(19)	−52.8	5150	11450	17600	19450
(29)	Core loss and friction	600	600	600	600	600
(30)	Net Torque = (28) − (29)	−653	4550	10850	17000	18850
(31)	Power output = S . (30)	−653	4460	10300	15300	14700
(32)	Efficiency = (31)/(24)		0.808	0.812	0.725	0.532

It will be noted that all the steps are indicated in the above. It is obvious that if a printed calculation form arranged as the above is used, the calculation of the complete performance characteristics of the single-phase induction motor is made comparable to a simple problem of bookkeeping, and can be done by a person without any technical training.

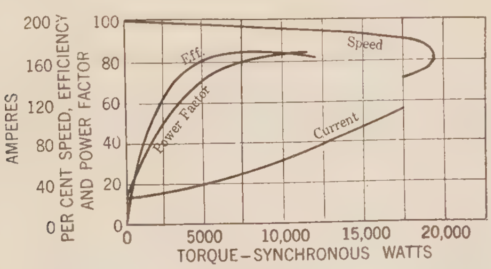


Fig. 3—Performance Characteristics of Single-Phase Induction Motor

The performance curves plotted from the above calculated values for current, torque, power factor, and efficiency are shown in Fig. 3.

As a further illustration, the method will be applied to the repulsion motor.

The Repulsion Motor

As usually built, the stator of a repulsion motor has a simple single-phase winding. This stator winding may be considered as made up of two windings, one which may be called the transformer winding and which is in inductive relation to the commutated winding, and

the other which may be called the field winding, which is at right angles to the axis of the commutated winding. According to the assumption of sine wave distributions of m. m. f., which is approximately realized in most cases, the transformer winding component will have $N \cos A$ effective turns, and the field winding component will have N sine A effective turns, where A is the angle in electrical degrees between the axis of the commutated winding as determined by the brush position and the transformer axis. The motor can be represented diagrammatically as in Fig. 4.

The same symbols that were used for the single-phase induction motor will apply for the repulsion motor and in addition we have,

I_3 = local short-circuit current in the coils short-circuited by the brushes.

r_3 = resistance of the local short circuits formed by the coils short-circuited by the brushes and the brush contacts.

The leakage reactance of the local short circuits is assumed the same as that of the rotor winding as a whole, viz., x_2.

We have, therefore, three circuits to consider in the repulsion motor, and three corresponding voltage equations. For the stator winding we have,

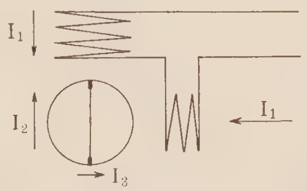


Fig. 4

$$E = j\,X_m(I_1 \cos^2 A - I_2 \cos A) + j\,X_m\,(I_1 \sin^2 A - I_3 \sin A) + (r_1 + j\,x_1)\,I_1 \qquad (20)$$

For the rotor winding proper,

$$O = -\,j\,X_m\,(I_1 \cos A - I_2) + (r_2 + j\,x_2)\,I_2 + S\,X_m\,I_1 \sin A - S\,(X_m + x_2)\,I_3 \qquad (21)$$

For the coils short circuited by the brushes,

$$O = -\,j\,X_m\,(I_1 \sin A - I_3) - S\,X_m\,(I_1 \cos A - I_2) + S\,x_2\,I_2 + (r_3 + j\,x_2)\,I_3 \qquad (22)$$

Solving for I_1, I_2 and I_3, we get the equations,

$$I_1 = E\,\frac{[r_2\,r_3 - (1-S^2)(X_m+x_2)^2 + j(r_2+r_3)(X_m+x_2)]}{U_2' + j\,W_2'} \qquad (23)$$

$$I_2 = E\,X_m\,\frac{[-S\,r_3 \sin A - (1-S^2)(X_m+x_2)\cos A + j\,r_3 \cos A]}{U_2' + j\,W_2'} \qquad (24)$$

$$I_3 = E\,X_m\,\frac{[S\,r_2 \cos A - (1-S^2)(X_m+x_2)\sin A + j\,r_2 \sin A]}{U_2' + j\,W_2'} \qquad (25)$$

Where

$$U_2 = -\,r_2\,X_m^2 \cos^2 A - r_3\,X_m^2 \sin^2 A - (r_2+r_3)(x_1+x_2)X_m - (r_2+r_3)\;x_1x_2 + r_1r_2r_3 - (1-S^2)r_1(X_m+x_2)^2$$

$$W_2' = r_1\,(r_2 + r_3)\,(X_m + x_2) + r_2\,r_3\,(X_m + x_1) + S(r_3-r_2)X_m^2 \sin A \cos A - (1-S^2)(X_m+x_2)\,[X_m\,(x_1 + x_2) + x_1\,x_2]$$

The components of the motor flux which react with the currents I_2 and I_3 to produce torque are the field flux Φ_f and the transformer flux Φ_t,

Where

$$\Phi_f = \frac{X_m\,I_1 \sin A - (X_m + x_2)\,I_3}{2\,\pi\,f\,N} \qquad (26)$$

and

$$\Phi_t = \frac{X_m\,I_1 \cos A - (X_m + x_2)\,I_2}{2\,\pi\,f\,N} \qquad (27)$$

The torque developed by the motor at any speed is, in synchronous watts,

$$T = 2\,\pi\,f\,N\,[\,(I_2 \,.\, \Phi_f) - (I_3 \,.\, \Phi_t)\,]$$

where $(I_2 \,.\, \Phi_f)$ and $(I_3 \,.\, \Phi_t)$ represent the products of the in-phase components of I_2 and Φ_f, and I_3 and Φ_t, respectively. Substituting for the currents and fluxes their values from equations (**23**) to (**27**) and multiplying out, we get,

$$T = \frac{E^2\,X_m^2}{U_2'^2 + W_2'^2}\left\{\begin{array}{l}(r_3^2 - r_2^2)\,(X_m + x_2)\sin A \cos A \\ +(r_3 \sin^2 A + r_2 \cos^2 A) \\ \,[-S\;r_2\;r_3 + S(1-S^2)(X_m+x_2)^2]\end{array}\right\} \qquad (28)$$

The no-load speed is obtained by solving the cubic equation that is obtained by putting $T = 0$ in the above. An approximate solution is,

$$S_0 \simeq \sqrt[3]{1.5 + \frac{r_3}{X_m\,(\tan A + \frac{r_2}{r_3}\cot A)}}$$

This approximate equation is theoretically much more accurate than any calculated value of r_3 can be expected to be. Its chief value is to show how the no-load speed of a repulsion motor might be affected by changes in design.

Special simplified formulas for the current and torque at synchronous speed or at standstill can be obtained by putting $S = 1$ or $S = 0$ in equations (**23**) and (**28**). Slight approximations can then be made by which the equations are reduced to rather simple formulas which need not be given here.

The performance characteristics of the motor can be calculated completely from equations (**23**) and (**28**). For calculation purposes, it is advisable to divide the numerators and denominators of these equations by $(X_m + x_2)^2$ and $(X_m + x_2)^4$ as in the case of the single-phase induction motor. This gives,

$$I_1 = \frac{M_2 + j\,N_2}{U_2 + j\,W_2}$$

$$T = E^2\,\frac{G_9 + S\,G_{10} + (1 - S^2)\,G_{11}}{U_2^2 + W_2^2}$$

Where

$$M_2 = G_1 + (1 - S^2)\,G_2$$
$$N_2 = G_3$$
$$U_2 = G_4 + (1 - S^2)\,G_5$$
$$W_2 = G_6 + S\,G_7 + (1 - S^2)\,G_8$$

The complete expressions for G_1 to G_{11} inclusive are given in the following sample calculation.

Performance Calculation of Repulsion Motor

Motor design constants:

$r_1 = 1.1$
$r_2 = 3.5$
$r_3 = 100$
$x_1 = 2.8$
$x_2 = 2.8$
$X_m = 60$
$A = 15°$

Core loss and friction = 110 watts

$$G_1 = E\,\frac{r_2\,r_3}{(X_m + x_2)^2} = 19.5$$

$$G_2 = -E = -220$$

$$G_3 = E\,\frac{r_2 + r_3}{X_m + x_2} = 363$$

$$G_4 = -(r_3 \sin^2 A + r_2 \cos^2 A)\left(\frac{X_m}{X_m + x_2}\right)^2$$

$$-\left(\frac{r_2 + r_3}{X_m + x_2}\right)\left(x_1 + \frac{x_2\,X_m}{X_m + x_2}\right) + \frac{r_1\,r_2\,r_3}{(X_m + x_2)^2} = -17.98$$

$$G_5 = -r_1 = -1.1$$

$$G_6 = \frac{1}{X_m + x_2}$$

$$\left(r_1\,r_2 + r_1\,r_3 + r_2\,r_3\,\frac{X_m + x_1}{X_m + x_2}\right) = 7.39$$

$$G_7 = (r_3 - r_2)\left(\frac{X_m}{X_m + x_2}\right)^2 \sin A \cos A = 22.0$$

$$G_8 = -\left(x_1 + \frac{x_2\,X_m}{X_m + x_2}\right) = -5.47$$

$$G_9 = +\frac{X_m^2\,(r_3^2 - r_2^2)\sin A \cos A}{(X_m + x_2)^3} = 36.3$$

$$G_{10} = -\frac{X_m^2\,r_2\,r_3}{(X_m + x_2)^4}$$

$$(r_3 \sin^2 A + r_2 \cos^2 A) = -0.80$$

$$G_{11} = \left(\frac{X_m}{X_m\,x_2}\right)^2$$

$$(r_3 \sin^2 A + r_2 \cos^2 A) = 9.05$$

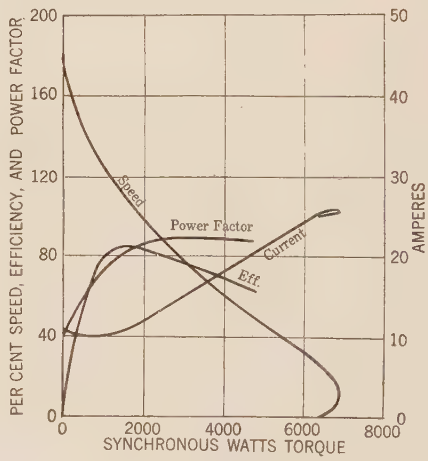


Fig. 5—Performance Characteristics of Repulsion Motor

The performance curves corresponding to the following calculated values are shown in Fig. 5.

It will be noted that this calculation form is, in general outline the same as that used for the single-phase induction motor, practically the only differences being in the expressions for the constants F_1, F_2, etc., and G_1, G_2, etc.

The single-phase induction motor and the repulsion motor have been chosen to illustrate the general method of analysis by the cross-field theory on account of their relative simplicity. The same general method might be applied to machines of more complicated types, such as those having four or more circuits to consider, but the method of procedure would be essentially the same, and the results would merely be somewhat more complicated. The analytical solution of such a motor by the same general method has been given in a previous paper. (Trans. A. I. E. E., 1924, p. 1048.)

Performance Calculation of Repulsion Motor—(*Continued*)

	S	0	0.75	1.00	1.25	1.80
	$1 - S^2$	1	0.4375	0	−.5625	−2.24
	$S(1 - S^2)$	0	0.328	0	−.703	−4.03
(1)	G_1	19.5	19.5	19.5	19.5	19.5
(2)	$(1 - S^2)\ G_2$	−220	−96.3	0	123.8	493.
(3)	M_2 = (1) + (2)	−200.5	−76.8	19.5	143.3	512.5
(4)	$N_2 = G_3$	363	363	363	363	363
(5)	G_4	−17.98	−17.98	−17.98	−17.98	−17.98
(6)	$(1 - S^2)\ G_5$	−1.1	−0.48	0	.62	2.46
(7)	U_2 = (5) + (6)	−19.08	−18.46	−17.98	−17.36	−15.52
(8)	G_6	7.39	7.39	7.39	7.39	7.39
(9)	$S\ G_7$	0	16.50	22.0	27.50	39.6
(10)	$(1 - S^2)\ G_8$	−5.47	−2.39	0	3.08	12.26
(11)	W_2 = (8) + (9) + (10)	1.92	21.50	29.39	37.97	59.25
(12)	$M_2\ U_2$	3820	1420	−350	−2490	−7950
(13)	$N_2\ W_2$	696	7800	10680	13750	21500
(14)	(12) + (13)	4516	9220	10330	11260	13550
(15)	$N_2\ U_2$	−6930	−6700	−6520	−6300	−5640
(16)	$-\ M_2\ W_2$	380	1655	−570	−5450	−30400
(17)	= (15) + (16)	−6550	−5045	−7090	−11750	−36040
(18)	U_2^2	364	341	323	302	241
(19)	W_2^2	4	462	863	1440	3510
(20)	= (18) + (19)	368	803	1186	1742	3750
(21)	I_{1a} = (14)/(20)	12.28	11.5	8.75	6.45	3.62
(22)	I_{1b} = (17)/(20)	−17.8	−6.3	−5.98	−6.75	−9.6
(23)	$I_1 = \sqrt{I_{1a}^2\ I_{1b}^2}$	21.6	13.15	10.55	9.35	10.25
(24)	Power factor = (21)/(23)		0.875	0.83	0.69	0.35
(25)	Power input = E . (21)		2530	1920	1420	796
(26)	G_9	36.3	36.3	36.3	36.3	36.3
(27)	$S\ G_{10}$	0	−0.6	−0.8	−1.0	−1.4
(28)	$S\ (1 - S^2)\ G_{11}$	0	3.0	0	−6.3	−36.4
(29)	= (26) + (27) + (28)	36.3	38.7	35.5	29	−1.5
(30)	$T = E^2$. (29)/(20)	4790	2340	1450	805	−19
(31)	Core loss and friction	110	110	110	110	110
(32)	Net torque = (30) − (31)	4680	2230	1340	695	−129
(33)	Power output = S . (32)		1674	1340	868	−232
(34)	Efficiency = (33)/(25)		0.66	0.70	0.61	−0.29

The Calculation of Magnetic Attraction
By the Aid of Magnetic Figures

BY TH. LEHMANN[1]

Non-member

Synopsis.—*The present paper treats of the following matters:*

1. *Simplification of the physical formula for magnetic attraction*
2. *Definition of magnetic reluctance when the magnetic field is bounded by non-equipotential surfaces*
3. *Calculation of the virtual variation in magnetic reluctance due to any displacement of the limiting surfaces*
4. *Demonstration of the theorem that the magnetic attraction between two ferromagnetic bodies depends only upon their common magnetic fluxes ϕ and upon the virtual gradient of its air-reluctances R_o, and that the formula*

$$F_l = \frac{\phi^2}{8\pi} \frac{\delta R_o}{\delta_l}$$

which gives the attraction along any given direction l is as general and as exact as the formulas of physics

5. *Direct deduction of magnetic attraction from the lines of magnetic flux depicted by a magnetic figure without resorting to the components of the magnetic field.*

The method used is developed by the application of the well-known principles of the potential energy function to the magnetic flux in the air-gap. Paths for the magnetic flux are established across the air-gap between the two ferromagnetic surfaces bounding the air-gap, by decomposing the magnetic flux into elemental tubes of magnetic force, the envelopes of which enclose spaces in which the flux is constant. The element of boundary-surface intersected by each elemental tube at the two boundary-surfaces encloses an equal number lines of magnetic flux, irrespective of the magnetic density at these points. By replacing the element of boundary-surface by its geometrical projection on a plane normal to the axis of the elemental tube, an equivalent equipotential surface is obtained at each end of the elemental tube. Any non-equipotential surface bounding an air-gap can thus be replaced by an equivalent equipotential surface composed of an aggregation of elemental equipotential surfaces which produce denticulations in the contour of the boundary-surface. It becomes possible, in this way, to evaluate magnetic reluctance and magnetic attraction by reference to summations of elemental magnetic tubes and without the necessity of considering directly the magnetic density of the magnetic field at any point. The potential of each elemental tube of magnetic force depends only upon the potentials at its ends, at the boundary-surfaces, it being entirely independent of the path followed by the tube in traversing the air-gap.

* * * * *

I. Introduction

The resultant magnetic effort, F, which is experienced by a soft iron body in a medium whose permeability is independent of the field, H, can be calculated by means of the known formula

$$F = \frac{1}{8\pi} \int_s \{2\,H\,(B, N) - N\,(H, B)\}\, d\,S \qquad (\mathbf{1})$$

in which N is the external unit vector which is normal to the surface-element $d\,S$, H and B being the vectors of the magnetic field and induction at the same point.

By means of equation (**1**), the resultant force, F, can be calculated whenever the distribution of the magnetic field along the external surface of the magnetic body is known. When that body is surrounded by air or like medium, the formula (**1**) can be further simplified; but even in that case, there are no analytical solutions in the majority of the cases of magnetic field distribution met with in practise, so that, as a rule, all that can be done is to obtain the graphical integration of equation (**1**) by deducing the values of the magnetic field from a chart of its lines of magnetic flux. It is possible, now, to determine these values within one per cent[2].

This method of evaluation of the quantity indicated by equation (**1**) is not free from error, owing to the points of saturation which occur at the sharp angles and at the narrow portions of the ferromagnetic material enclosing the slots.

For these reasons it seems worth while to inquire whether magnetic attraction could not be deduced directly from the lines of force shown in a magnetic figure without the necessity of first obtaining the components of the magnetic field and then recombining them tensorially. It so happens that this is possible within the entire range of validity of equation (**1**).

In the present paper the only case considered will be that of the attraction between ferromagnetic bodies that are separated by a medium like air, this case being of more immediate interest.

II. Transformation of the Physical Formula for Attraction

In (**1**), let $\{\,2\,H\,(B, N) - N\,(H, B)\,\} = P$. This quantity is a linear vectorial function of the normal unit-vector N. By putting this expression in the form $a\,P + b\,H + c\,N = 0$, it is seen that P, H, and N, and also B when $B \parallel H$, are situated in the same plane. Moreover, the vector H bisects the angle formed between P and N (Fig. 1)[3] as is seen at once by taking the scalar product of P and H, and observing that $P^2 = B^2\,H^2$. This allows P to be written in simpler form.

Let us use the term *"directed algebraical product"* of two vectors, H and B, to designate the vector the length of which is equal to the algebraical product of the scalar values of H and B, and the angle of which, with the

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1. Consulting Engineer, Urmatt, France.
2. See *Revue Générale de l'electricité*, 1923, Vol. XIV, pp. 347 and 395.
3. See, for instance, A. Vaschy, "Théorie de l'Electricité," 1896, p. 64.

To be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926.

outward normal N, is equal to the sum of the angles, α, which H and B make with N; that is to say, $2\,\alpha$ when $B \parallel N$. This vector, which is parallel to the same plane as N, H and B, will be symbolized by $(\overline{B}\,\overline{H})_{2\alpha}$, so that for an iron body surrounded by air, formula (**1**) may be expressed in the following form:

$$F = \frac{1}{8\,\pi} \int_s B^2_{2\alpha}\, d\, S \qquad (\mathbf{2})$$

Equation (**2**) may be considered a generalization of the ordinary formula of Maxwell, with which it becomes identical when $\alpha = 0$.

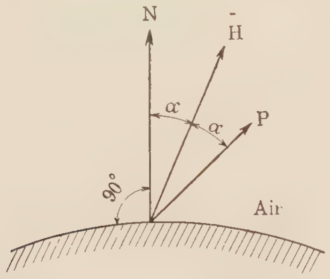

Fig. 1

It is seen at once that the algebraical value of the quantity to be integrated P, P is always equivalent to B^2 whatever may be the angle of incidence, α, of the magnetic field. In air, the tensorial ellipsoid consequently becomes a sphere. For the condition $\alpha = 0$, the integration is performed along a level surface, and $P = \overline{B_0}^2$ has the direction of N. For an angle of incidence $\alpha = 45$ deg., the elemental effort $P = \overline{B_{\pi/2}}^2$ is tangential to the surface. Finally, if the integration is performed along a surface generated by lines of magnetic flux, and more especially along a line of plane flux, we have

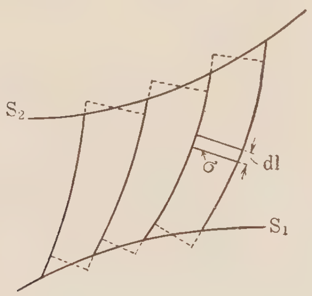

Fig. 2

$2\,\alpha = \pi$, and $P = \overline{B}^{\,2}$ is now directed in a direction contrary to that of N. Since the direction of P is obtained by simply reflecting N with respect to B, the application of formula (**2**) is a very simple matter.

III. Definition of the Reluctance Between two Non-Equipotential Surfaces which are Separated by an Air-Space

Let us subdivide the air-space between two non-equipotential surfaces, S_1 and S_2, (Fig. 2), into n very thin aliquot or subsidiary tubes having the reluctances $\rho_1, \rho_2, \rho_3, \ldots$, and let us replace the oblique bases of each tube by orthogonal bases having the same distance between centers. The elemental tubes being now limited by orthogonal bases, their reluctances can now be defined in the ordinary simple manner. It is known, moreover, that, in a medium of constant permeability, the magnetic energy of a Laplacian or vortex magnetic field is given by the volume-integral

$$W_m = \frac{1}{8\,\pi} \int B\,H\,d\,v$$

Integrating across the air-gap, along each tube, by tube-elements of sectional area σ and length $d\,l$, we will have

$$W_m = \frac{1}{8\,\pi} \sum_1^n \int B^2\,\sigma\,d\,l = \frac{1}{8\,\pi} \sum_1^n \phi_k^2 \int \frac{d\,l}{\sigma}$$

$$= \frac{1}{8\,\pi} \sum_1^n \phi_k^2\,\rho_k$$

But since the flux, ϕ_k, of each aliquot tube is equal to the nth part of the total flux Φ, we have

$$W_m = \frac{1}{8\,\pi} (\Phi_n)^2 \sum_1^n \rho_k = \frac{\Phi^2}{8\,\pi} R_0 \qquad (\mathbf{3})$$

whence we deduce the total reluctance

$$R_0 = \frac{1}{n^2} \sum_1^n \rho_k \qquad (\mathbf{3'})$$

or, more precisely,

$$R_0 = \lim_{n = \infty} \frac{1}{n^2} \sum_1^n \rho_k \qquad (\mathbf{3''})$$

It is evident that, by defining the reluctance ρ_k of each tube in accordance with (**3″**), formulas (**3**) and (**3′**) will remain rigorously accurate, whatever may be the magnitude of the elemental tubes.

In principle, the reluctance R_0 between two non-equipotential surfaces may be defined by the aid of any drawing of magnetic tubes. If the fractional coefficients of the tubes be designated by $m_1 = \frac{\Phi}{\phi_1}$, $m_2 = \frac{\Phi}{\phi_3}$, $\ldots$ we obtain, for R_0, the following more general expression:

$$R_0 = \sum_1^n \frac{\rho_k}{m_k^2} \qquad (\mathbf{4})$$

The most frequent case is that where an arrangement of n tubes, conveying a total flux Φ, is composed of $n - 1$ aliquot tubes, each containing the flux $\phi_k = \frac{\Phi}{m}$ and a residual flux $\phi_n = \frac{\Phi}{m_n}$. The total reluctance then becomes equal to

$$R_0 = \frac{1}{m^2} \sum_{1}^{n-1} \rho_k + \frac{\rho_n}{m_n^2} \qquad (5)$$

IV. Demonstration of the Equivalence of the Formula $F_l = \frac{\Phi^2}{8\pi} \frac{\delta R_0}{\delta l}$ to Formula (2)

Let us represent in cross-section (Fig. 3) the origin of a very thin tube, 2 – 3, and of the adjacent tubes, 1 – 2 and 3 – 4. Let us make the plane of the drawing parallel with the magnetic field in the air-gap B,

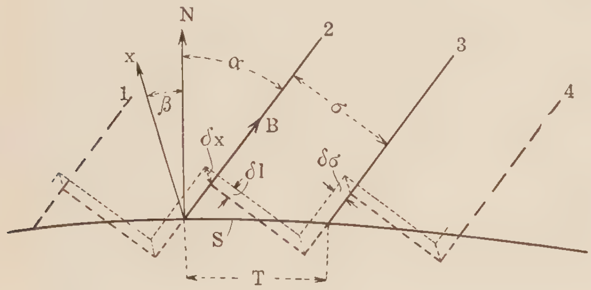

FIG. 3

and with the normal, N, with respect to the surface-element, S. The lines of magnetic flux being supposed to be very close to each other, no change will be caused in the reluctance of the tubes or in the external field if the oblique bases are replaced by orthogonal cross-sections through the same centers. Let us now displace the denticulated surface in a direction parallel to itself to the distance $d\,z$. All that need be considered is the projection $d\,x = d\,z \cos\eta$ of this displacement on the plane containing the vectors N and B, because any displacement of the surface-element S perpendicularly to that plane will have no influence on the reluctance of the tube under consideration. By taking any suitable unit of length for measuring the thickness of the tube in the direction perpendicular to the drawing, the width, σ, of the tube in the plane of the drawing can be made equal to its sectional area, and the intersections of its oblique base can be made equal to the surface-element, S.

Let (in Fig. 3) β designate the angle between $\delta\,x$ and the normal, N, and let α designate the angle of incidence of the vector, B. It will easily be seen that the displacement of the denticulated surface to the distance $d\,z$ causes in the tube of magnetic force a shortening equal to $d\,l = d\,x \cos(\alpha + \beta)$ in the direction of its length, and a decrease in its sectional area equal to $d\,\sigma = d\,x \sin(\alpha + \beta)$ over a length equal to $s \sin\alpha$. The result is that the reluctance of the portion of the tube thus modified is changed from $\rho = \frac{s \sin\alpha}{\sigma}$ to $\rho' = \frac{s \sin\alpha - \delta\,l}{\sigma - \delta\,\sigma}$, so that the variation in reluctance caused by the displacement of the surface-element, S, when $\sigma = s \cos\alpha$, and $s = S$, becomes equal to

$$\delta\,\rho = \frac{\delta\,x}{\sigma^2} \cos(2\,\alpha + \beta)\,S$$

$$= -\frac{\delta\,z}{\sigma^2} \cos\eta \cos(2\,\alpha + \beta)\,S \qquad (6)$$

Now, let $\frac{\Phi}{m_k} = B\,\sigma$ represent the magnetic flux in any tube. The summation of the values $\frac{\Phi^2}{8\,\pi} \frac{1}{m_k^2} \frac{\delta\,\rho_k}{d\,z} = -\frac{1}{2\,\pi} B^2 \cos(2\,\alpha + \beta)\,S$ along the whole surface will then, with the aid of (4), give us

$$\frac{\Phi^2}{8\,\pi} \sum \frac{1}{m_k^2} \frac{\delta\,\rho_k}{\delta\,z} = \frac{\Phi^2}{8\,\pi} \frac{\delta\,R_0}{\delta\,z},$$

from which, by passing to the limit, we obtain

$$\frac{\Phi^2}{8\,\pi} \frac{\delta\,R_0}{\delta\,z} = -\frac{1}{8\,\pi} \int_s B^2 \cos(2\,\alpha + \beta) \cos\eta\,d\,S \qquad (7)$$

It now becomes immediately apparent that the quantity under the integral sign is nothing more than the projection of the vector, $P = \overline{B_{2\alpha}}^2$ upon the direction of $\delta\,z$. Therefore, the formulas (2) and (1) lead to the same effort in any given direction δz, as the formula $\frac{F}{z} = \frac{\Phi^2}{8\,\pi} \frac{\delta\,R_0}{\delta\,z}$, and the three formulas are consequently equivalent to each other. This result can also be expressed vectorially as follows:

$$-\frac{\Phi^2}{8\,\pi} \times (\text{Virtual gradient of } R_0) = \frac{1}{8\,\pi} \int_s \overline{B_{2\alpha}^2}\,d\,S.$$

We shall now show that the attraction between two

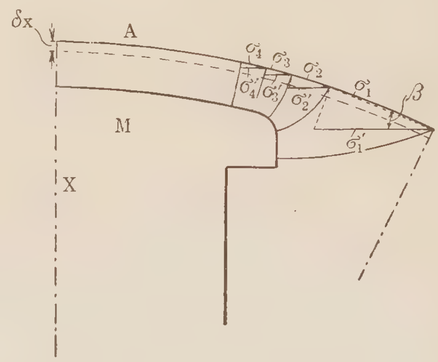

FIG. 4

bodies depends only upon the field that is common to both of them and that it can be evaluated without knowing the leakage-field.

V. Calculation of Magnetic Attraction by Means of the Common Field Only

A. Unsaturated circuits. Let us consider the attraction in a radial direction between a field-magnet M

with salient poles and the armature (or stator) A (Fig. 4), on the assumption that $\mu = \infty$ in the iron. For this purpose, let us suppose a virtual decrease equal to δx in the air-gap, as if the armature were brought closer in the direction of the axis (X) of the pole, and let us, for a moment, assume as being true, the physical figment that the external field is not disturbed in consequence of the displacement in question (δx). Under such conditions, the length of each tube of magnetic force will be decreased by an amount equal to $\delta x \cos \beta$, where β designates the angle between the normal to the surface S at the point under consideration and the direction of δx. Therefore, if σ is the sectional area of the tube as it emerges from the surface of A, the variation of its reluctance, ρ, will be $\delta \rho = -\dfrac{\delta x \cos \beta}{\sigma}$. The portion of the virtual energy pertaining to this tube, when ϕ is the flux, consequently becomes equal to $\delta T = \dfrac{\phi^2}{8\pi}\dfrac{\delta x \cos \beta}{\sigma} = \dfrac{B^2}{8\pi}\,\delta x \cos \beta\, \sigma$, and the elemental force along δx will be equal to

$$f_x = \frac{B^2}{8\pi}\,\sigma \cos \beta$$

which is evidently the projection upon δx of the force which is normal to σ, namely, $f = \dfrac{B^2 \sigma}{8\pi}$, in perfect accordance with formulas (**1**) and (**2**).

Inasmuch as the common flux ϕ, is generally the primary information available in practise, it is important to note that the total force of attraction F_x can be obtained without any integration, when the drawing shows m isometric tubes, by obtaining, along the armature, the value of the sum

$$F_x = -\frac{\Phi^2}{8\pi}\frac{\delta R_0}{\delta x} = \frac{\Phi^2}{8\pi}\frac{1}{m^2}\sum \frac{\cos \beta}{\sigma}$$

All that is necessary, therefore, is to obtain, at the place where the end-section, σ, of each tube emerges from the polar surface (A), the segments $\sigma' = \dfrac{\sigma}{\cos \beta}$, which are marked off by projection upon a line perpendicular to the direction of δx (see Fig. 4) by the normals to the chord of σ drawn (dotted in Fig. 4) between its two opposite edges. We thus obtain

$$F_x = \frac{\phi^2}{8\pi}\frac{1}{m^2}\sum \frac{1}{\sigma'} \tag{8}$$

The degree of precision of F_x naturally depends upon the number of isometrical tubes into which the useful flux is subdivided. When the drawing comprises $n - 1$ tubes, each containing the flux $\phi = \dfrac{\Phi}{m}$, and a residual tube containing the flux $\phi' = \dfrac{\Phi}{m'}$, it is evident that we shall have

$$F_x = \frac{\Phi^2}{8\pi}\left\{\frac{1}{m^2}\sum_{1}^{n-1}\frac{1}{\sigma_k - 1} \;\cdots\; + \frac{1}{m'^2}\frac{1}{\sigma_n'}\right\} \tag{8'}$$

Let us now reverse the roles by bringing the field-magnet closer to the armature by the distance δx in a direction parallel to the axis of the pole. In order to make the physical figment plausible, we must now assume (Fig. 5) that the magnetic field is displaced bodily with its excitation-winding, which is assumed to have a fixed relation with respect to the pole (M). The line of flux $1 - 2$ which starts from the neutral point, will be displaced upward by the distance δx in a direction parallel to itself, toward $1' - 2'$; and we now have to find the difference between the reluctances between the contours $1 - 2 - 3 - 4$ and $1' - 2' - 3' - 4'$. But, instead of measuring these differences along the armature, we shall totalize them along the pole and the line $1 - 2$. Along the polar surface, as far as the line $1' - 2'$, we shall obtain, as before, the segments $\sigma' = \dfrac{\sigma}{\cos \beta}$, where σ designates the sectional area of the tubes measured where they emerge from

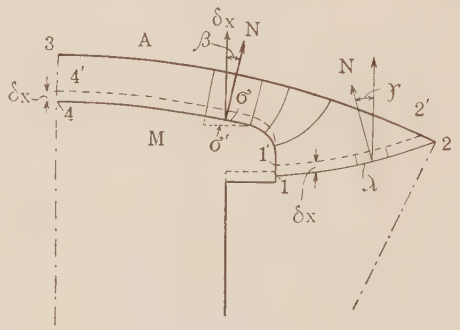

FIG. 5

the pole and β designates the angle between the normal N, to the chord of σ and the direction of δx. For the tube at the extreme right hand, there will be, in addition, a decrease in sectional area equal to $\delta x \cos \gamma$, where γ designates the angle between the direction of δx and the normal, N, to the line of flux at the point considered. The variation of reluctance per element of tube of length, λ, which results in the case of the last tube, in addition to the shortening, will be equal to

$$\delta \rho' = \frac{\lambda}{\sigma - \delta x \cos \gamma} - \frac{\lambda}{\sigma} = \frac{\lambda}{\sigma^2}\,\delta x \cos \gamma,$$

and the corresponding decrease of attractive force will be equal to

$$f_x' = -\frac{\phi^2}{8\pi}\frac{\delta \rho'}{\delta x} = \frac{B^2}{8\pi}\,\lambda \cos \gamma,$$

which is the geometrical projection on the pole-axis of a

force, $-\dfrac{B^2\,\lambda'}{8\,\pi}$ which is normal to λ. The same term may also be obtained with equations (**1**) and (**2**), by making the surface-integral pass over the polar face and the line of flux $1-2$ which ends at the neutral point.

The tube of magnetic force that is contiguous with the line $1-2$ is composed (Fig. 6) of two squares, the mean sectional areas of which may be replaced approximately by the chords, λ_1 and λ_2, of their average lengths. The quantities $\lambda_1' = \dfrac{\lambda_1}{\cos\,\gamma_1}$ and $\lambda_2' = \dfrac{\lambda_2}{\cos\,\gamma_2}$ correspond to and can be obtained directly from segments cut off from a horizontal line (Fig. 6) by the perpendicular lines erected at their extremities in each case; and with the aid of these quantities, we finally have, in the case of m aliquot tubes of magnetic force,

$$F_x = -\frac{\phi^2}{8\,\pi}\,\frac{\delta\,R_0}{\delta\,x}$$

$$= \frac{\phi^2}{8\,\pi}\,\frac{1}{m^2}\left\{\sum\frac{1}{\sigma'} - \left(\frac{1}{\lambda_1'} + \frac{1}{\lambda_2'}\right)\right\} \quad (\mathbf{9})$$

It is therefore possible to evaluate the virtual derivative,

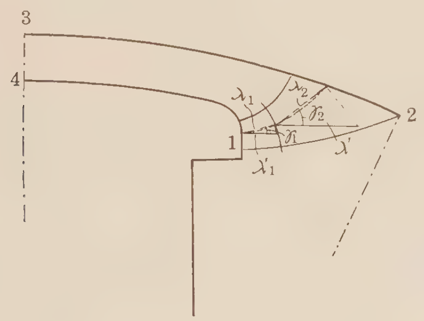

FIG. 6

$\dfrac{\delta\,R_0}{\delta\,x}$, *from the original drawing of the magnetic field, without representing the displacement $\delta\,x$ and without introducing the components of the magnetic field.*

It should be noted that the virtual work is equal to the energy contained in the zone involved only when the armature is displaced. If, instead, the magnetic field-pole and its winding are displaced, the magnetic energy contained in the area embraced by the polar base of the useful flux, $1-4$ (Fig. 5) should be reduced by an amount equal to the potential energy contained in the zone embraced by the extreme lines $1-2$ of the common flux.

Example. Let us take as an example, the magnetic figure (Fig. 7) reproduced from Fig. 19 in the *"Revue Generale de l'Electricite,"* 1923, Vol. XIV, p. 397. After the fourth magnetic tube, counting from the neutral point, the lines of magnetic flux are radial, and they constitute, between that point and the polar axis, 6.4 unit tubes; so that the common flux, ϕ, per half pole consists of 10.4 unit-tubes. The air-gap being equal to 1.2 cm., and the polar half-pitch being equal to 9 cm., we have, for the sectional areas along the armature, reckoned from the neutral point:

2.85 cm.; 0.97 cm.; 0.71 cm.; 0.62 cm.; 6.4/0.6 cm.

The fractional coefficients are $m = 10.4$ for the first four tubes and $m' = 10.4/6.4$ for the last tube; so that, for the radial attraction per half polar pitch, we have:

$$F_x = \frac{\phi^2}{8\,\pi}\,\frac{1}{10.4^2}\left[\frac{1}{2.85} + \frac{1}{0.97} + \frac{1}{0.71} + \frac{1}{0.62} + \frac{6.4}{0.6}\right]$$

$$= \frac{\phi^2}{8\,\pi}\,\frac{1}{10.4^2}\,.\,15.06$$

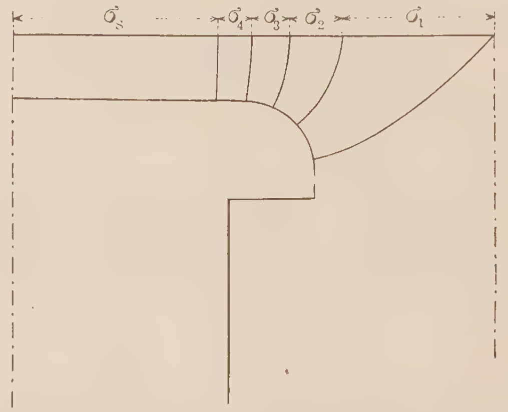

FIG. 7—DETERMINATION OF THE MAGNETIC ATTRACTION OF THE ARMATURE

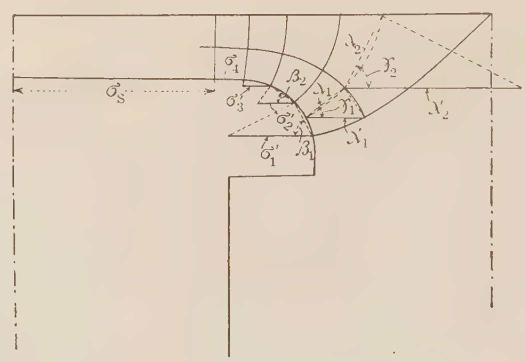

FIG. 7 A—DETERMINATION OF THE MAGNETIC ATTRACTION OF THE FIELD

Let us now start from the field-pole. The bases of the first three tubes that emerge from the polar surface are no longer horizontal, and it is necessary to begin by erecting perpendicular lines on the chords of σ and to obtain in a horizontal direction (see Fig. 7A) the values of $\sigma' = \dfrac{\sigma}{\cos\beta}$; which gives us the following values; $\sigma_1' = 1.57$ cm.; $\sigma_2' = 0.70$ cm.; $\sigma_3' = 0.34$ cm.; and we can then point off directly the values $\sigma_4 = 0.55$ cm. and $\sigma_5 = 6.4/0.6$ cm. We still have to obtain,

on the line of median flux of the first tube (shown dotted), the segments $\lambda_1' = \dfrac{\lambda_1}{\cos\gamma_1}$ and $\lambda_2' = \dfrac{\lambda_2}{\cos\gamma_2}$, which may be cut off along any horizontal lines whatever by the lines perpendicular to the chords of the curvilinear elements λ_1 and λ_2 erected at their extremities. These values are found to be: $\lambda_1' = 1.10$ cm., and $\lambda_2' = 3.40$ cm.

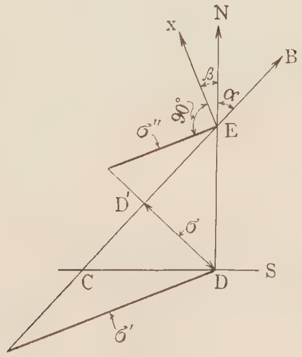

FIG. 8

The radial effort exerted per half pole pitch is thus found to be equal to

$$F_x = \frac{\phi^2}{8\pi}\frac{1}{10.4^2}$$

$$\left[\frac{1}{1.57}+\frac{1}{0.70}+\frac{1}{0.54}+\frac{1}{0.53}+\frac{6.4}{0.6}-\frac{1}{1.10}-\frac{1}{3.4}\right].$$

$$= \frac{\phi^2}{8\pi}\frac{1}{10.4^2}\,.\,15.20$$

The difference between this value and the preceding one is barely one per cent; which seems satisfactory if we bear in mind that for the whole of the half distance between the two poles only one tube of magnetic force has been assumed. The armature in Fig. 7, was assumed to be rectilinear, instead of curved, in order to simplify the comparison with the algebraical formula which can be established for that case. The inclination of the polar axes does not in any way modify the method of calculation, and the same results should always be obtained whether we start from the armature or from the field-pole.

B. Saturated Circuits. The physical figment that a displacement does not disturb the external field leads us immediately, by the aid of (**6**), to expressions for an armature in which there is no current,

$$F_x = \frac{\phi^2}{8\pi}\sum\frac{\cos(2\alpha+\beta)}{m^2\,\sigma\cos\alpha}, \qquad (\mathbf{10})$$

and for a field-pole which is driving its field without alteration,

$$F_x = \frac{\phi^2}{8\pi}$$

$$\left\{\sum\frac{\cos(2\alpha+\beta)}{m^2\,\sigma\cos\alpha}-\frac{1}{m_n^2}\left(\frac{\lambda_1}{\cos\gamma_1}-\frac{\lambda_2}{\cos\gamma_2}\right)\right\} \qquad (\mathbf{10'})$$

Let us consider (Fig. 8) the base $C\,D$ of a tube having the thickness $D\,D' = \sigma$, which emerges from an element $C\,D$ of the surface, S, of the iron, at an angle α with respect to the normal $D\,E$ to $C\,D$. We can then obtain the projection of the superficial force f_x, corresponding to this tube, in a direction x, forming an angle β with $D\,E$, by constructing directly

$$f_x = -\frac{\phi^2}{8\pi}\frac{\delta\rho}{\delta x} = \frac{\phi^2}{8\pi}\frac{\cos(2\alpha+\beta)}{\sigma\cos\alpha}.$$

But it is often easier to decompose

$$\frac{\delta\rho}{\delta x} = \frac{1}{\sigma'} - \frac{1}{\sigma''}$$

$$= \frac{\cos(\alpha+\beta)}{\sigma} - \frac{\tan\alpha\sin(\alpha+\beta)}{\sigma}$$

and to obtain σ' and σ'' from Fig. 8 by cutting off segments on the perpendiculars to x emerging from D and E through the mean vector of the field B passing through C on the one hand and through the normal to the vector, passing through D, on the other hand. In the case of the field-pole it is still necessary to add the terms $\dfrac{\lambda}{\cos\gamma}$ which come from the extreme tubes of the common flux and which are determined as before.

When the magnetic figure comprises one or more lines of equal potential, the calculation becomes simpler by making the summation along any contour whatever, such as $A\,B\,C\,D\,E$ (Fig. 9) composed of lines of flux and of lines of equal potential, ending at the neutral points of the armature, or, in more general manner,

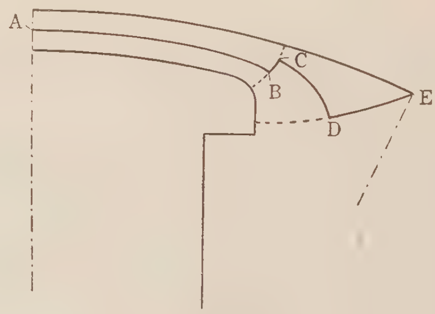

FIG. 9

ending at boundary points of the common field. The values of $\sigma' = \dfrac{\sigma}{\cos\beta}$ and of $\lambda' = \dfrac{\lambda}{\cos\gamma}$ may be obtained, as explained in paragraph A, from the sections σ on the equipotential lines and the segments λ on the isometric lines of flux, by noting that the terms

$\frac{1}{\sigma}$ are of the same sign as the areas swept over, where-

as the terms $\frac{1}{\lambda'}$ are of contrary sign.

The equivalence of the process can be easily demonstrated by transforming, by means of the generalized form of Green's theorem, the surface-integral (**1**) into a volume-integral:

$$\int_s S\, P\, d\, S = \int \{2\, H \operatorname{div} B - H^2 \operatorname{grad} \mu - 2\, (B, \operatorname{rot} H)\}\, dv \qquad (\mathbf{11})$$

In the space in the air-gap which is traversed by the useful flux we have, inside any closed aerial surface, $\operatorname{div} B = 0$; $\operatorname{grad} \mu = 0$; $\operatorname{rot} H = 0$; therefore, we will have

$$\int_S P\, d\, S = 0 \qquad (\mathbf{12})$$

Let us now suppose that the air-gap is swept over once by the surface of the armature, for a distance equal to one polar division $0_1\, I\, 0_2$ (Fig. 10) and a second time by a string of any kind whatever, such as 0_1 II 0_2 which extends between the same points 0_1 and 0_2 of the armature. Multiplying (**12**) scalarly by the displace-

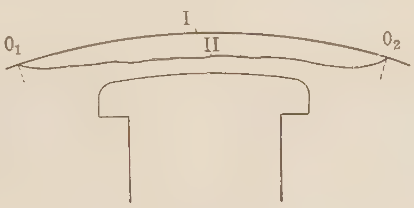

Fig. 10.

ment $\overline{\delta\, x}$, and integrating along the closed contour 0_1 I 0_2 II 0_1, we have:

$$\int_s (\overline{\delta\, x}, \overline{B_{2\alpha}{}^2})\, d\, S = 0; \text{ whence}$$

$$\int_{0_1 I\, 0_2} (\overline{\delta\, x}, \overline{B_{2\alpha}{}^2})\, d\, S = \int_{0_1 II\, 0} \overline{\delta\, x}, \overline{B_{2\alpha}{}^2})\, d\, S; \qquad (\mathbf{13})$$

or, on bringing (**13**) closer to the identity (**7**), we see that

$$(\delta\, R_0)_{\mathrm{I}} = (\delta\, R_0)_{\mathrm{II}}$$

It is, therefore, possible to determine the virtual variation of the reluctance, on the assumption that the air-gap is cut through by any contour whatever passing through the neutral points 0_1 *and* 0_2 *of the armature.* This manner of proceeding has advantages in the case of windings placed in slots (as in turbo generators).

The physical formulas for magnetic attraction are not much used in practise. Is this due to the hypotheses used in physics? It cannot be denied that, at first glance, our practical intuition, clarified by the idea of the magnetic circuit, finds it difficult to accept the figment which excludes any disturbance of the field during a virtual displacement. But this figment, although it may lead to a state of unbalance, is, in general, justified by observing that, in accordance with Thomson's theorem, one of the two neighboring states of distribution corresponds to a minimum of potential energy.

VI. Applicability of the Different Formulas

Theoretically, formulas (**1**) and (**2**) enable the attraction to be evaluated whenever the magnetic field in the air-gap is known along the whole surface. But since no analytical solutions that are of interest in practise are available in the majority of cases the best we could hope to do would be to obtain the integration of these formulas graphically after the values of the magnetic flux have been deduced from a drawing of the lines of flux. And even this calculation becomes uncertain in the neighborhood of the slots for the windings, on account of the points of saturation found at the sharp corners and narrow parts of the cores that close around the slots. On that account the integration is rendered possible only when the surface of integration is situated at a suitable distance from the limiting surfaces. It is therefore necessary to have a complete survey of the magnetic field in the air-gap. Moreover, formulas (**1**) and (**2**) are no longer applicable when the surface of integration passes through a medium the magnetic permeability of which is a function of H.

The formula $F_1 = \frac{\phi^2}{8\,\pi}\, \frac{\delta\, R_0}{\delta\, l}$ makes it possible to

evaluate the magnetic attraction in the case of any ferromagnetic body surrounded by a medium of constant permeability (air) without the necessity of taking into account the components of the field. The permeability of the body may or may not depend upon the field. In the form in which the formula is completed by the saturation-term[4], it can also be used when the permeability of the external medium depends upon the field. It is then possible, moreover, to do without the magnetic figures of the lines of flux, provided the reluctance, R_0, of the air-gap is known as a function of the extent l, of the air-gap, It is also more easy, by means of this formula, to note critical values of the effort of attraction near points of contact, where the attraction may become more than double, even when the flux is assumed to be maintained constant by means of equipotential connections.

VII. Conclusions

The magnetic effort exerted upon an assemblage of ferromagnetic bodies and of currents, surrounded by air as a medium, is determined by the corresponding fluxes, ϕ and by the virtual gradient of their air-reluctances, R_0.

The formula $F_1 = \frac{\phi^2}{8\,\pi}\, \frac{\delta\, R_0}{\delta\, l}$ is as exact and as

4. This case is treated in "*Revue Genérale de l'Electricité*," Vol. XV.

general as the formulas of physics. It has the advantage over them that besides giving an algebraical solution, it renders possible the evaluation of magnetic attraction by the direct utilization of the lines of magnetic flux of a magnetic figure, without the necessity of first determining the components of the field and then recombining them tensorially.

In a general way, the attraction between two bodies depends only upon the field common to them both. That is still true when the two fields have nothing more in common than their lines of separation (the case of the ideal short-circuit); and the mutual magnetic effort is then determined entirely by the value of the field along these lines of separation.

Discussion at Pacific Coast Convention

APPLICATION OF ELECTRIC PROPULSION TO DOUBLE-ENDED FERRY-BOATS

(Kennedy and Smith)

Seattle, Washington, September 16, 1925

H. F. Harvey, Jr.: About the only comment which I have to offer is that sufficient emphasis has not been laid on the maneuvering feature. With direct control from each pilot house it is very evident that the one in charge can maneuver the boat more easily than by means of the ordinary signals to the engine room.

I believe that thus far most ferry-boats with electric drive are used on fairly long runs. Such runs do not show to advantage the speedier maneuvering, either when entering or leaving the slips. For short runs as between New York and Jersey City, or between Camden and Philadelphia, electric drive would show a decided advantage in this respect.

Ferry-boats are usually operated in congested waters where it is very necessary to have close control of the vessel in order to avoid accidents. Electric drive, I believe, affords quicker stopping and reversing than any other drive. Too much emphasis, therefore, cannot be placed upon the superior maneuvering qualties of electrically driven ferry-boats.

F. K. Kirsten: There has been no mention made in the paper as to the design of the propellers involved in ferry-boat propulsion. It seems that these boats are designed to travel in either direction with practically the same propeller showing. As a consequence, some design must be used on these particular ferry-boat propellers differing from that used in ordinary steamers. I would like to know if any particular statements could be made in that direction.

M. J. Whiteman: I should like to know if it is possible with a ferry-boat having four-propeller drive to rotate the boat on a center or pivot in order to make quick turns.

A. Kennedy Jr.: Mr. Whiteman asked if it is possible with an electrically-driven ferry-boat to pivot the boat in order to make quick turns, and also the number of electrically driven ferry-boats that are in operation. All electrically driven ferry-boats use the same method of steering as that used on reciprocating steam engine driven ferry-boats, that is, they use one rudder. I do not know of any way to make a ferry-boat pivot in order to make quick turns unless some change is made in the design of the boat.

At the present time there are eight electrically driven ferry-boats in operation, three in New York, four in San Francisco, and one at Poughkeepsie. These, I believe, are the only ones, but of course, others are being considered.

Professor Kirsten asked whether or not it was necessary to modify the design of the propellers for electrically driven ferry-boats. Normally, with steam engine driven ferry-boats, a compromised propeller design is used, as it is necessary to use the face and back of the blades. A good deal of work has been done trying to improve the over-all propulsive efficiency by decreasing the amount of power required to drive the forward propeller. As far as I know, no one has been able to improve the over-all propulsive efficiency by using this specially designed propeller, but they have reduced the power required to drive the forward propeller.

With electric drive it is possible to use a standard propeller for the simple reason that the bow propeller does not do any work. Only the face is used of the propeller for driving, whereas with the reciprocating steam engine connected to a through shaft a special design is made as the back of the blades is normally used on the forward propeller to assist in driving the ferry-boat.

A HIGH-VOLTAGE DISTRIBUTING SYSTEM[1]

(Glen H. Smith)

Seattle, Washington, September 17, 1925

M. T. Crawford: In Mr. Smith's paper he has referred to the use of a high-voltage primary distribution system, and some reference is also made in Mr. Kelley's paper, to the use of 12,000-volt primary system.

It occurs to me that in following a far-sighted policy, there would be some question as to whether such a high voltage should be used for primary distribution in a city area. There are several angles to the situation. Fundamentally high voltages are of value to cover distances. In distributing light and power in a large city, very large blocks of load can be obtained within short distances. In suburban areas around the large city, considerable distance has to be covered before any considerable amount of power is obtained. For that reason it has been the practise of the company with which I am connected to employ the high-voltage distribution primarily in the suburban area where one distributing substation can serve a radius of 10 to 15 mi., without having any unusually large load entrusted to its care.

In looking into the future of city distribution, we anticipate loads of such size and magnitude as to give load densities which would result in several hundred thousand kilowatts or more being supplied by one distributing substation. If 10,000 or 15,000 volts is used for primary purposes and if sufficient area is covered to make full economic use of such voltage, this would, it is felt, entrust more different consumers' services into the hands of this one substation than might be considered good policy, considering the importance of continuity of service to such a large number of people. The other angles to the use of the high voltage are, first, that it takes considerably more pole space, second, that transformers are more expensive, and third, that cable costs are higher. Such portions of the systems as have to be either submarine or underground will have to be handled by cables, and statistics collected by the National Electric Light Association indicate that in operating a large mileage cable failures increase rapidly in proportion to the voltage.

The high-voltage distribution system in the city of Seattle has worked out very satisfactorily and I think the engineers are to be commended for having secured such results. I would like to ask Mr. Smith, however, if the increase in railway load which has recently occurred and will continue will not result in fluctuating loads on his 26-kv. network, which will introduce

1. A. I. E. E. Journal, October, 1925, p. 1104.

some difficulties in regulation and, may force a change in this policy. We have found where our load is largely lighting, we can use 13-kv. primary distribution very successfully, installing a 13-kv. automatic voltage regulator at the substation, to regulate the entire bus, serving an area within a 15 mi. radius with little or no supplementary regulation.

Where fluctuating power loads are to be handled together with a considerable amount of railway, this has not been possible, and it has been more economical, besides seeming to us better policy from the far-sighted point of view of future loads and service to the public, to install distributing stations and distribute at a lower primary voltage.

C. A. Heinze: There has been considerable discussion in these distribution papers on the matter of distribution at voltages of approximately 33 kv. Mr. Smith describes one at 26 kv. which is practically 33 kv. In Los Angeles, we have an area that is very lightly loaded, with the result that to place a network of low-voltage lines over that area would have called for considerable investment, not warranted by revenues. We were rather fortunate in this particular case to have two power houses, one on each side of the area. This permits us to carry straight line voltage on the 33-kv. lines between these two power houses.

Now, with a system plan, the system can be developed as follows: The first step to feed consumers from this 33-kv. line is to put a transformer on a pole, stepping down from 33 kv. to 4.4. kv., three-phase, three-wire delta. From this transformer we distribute a distance of from one to two miles each way, picking up the small consumers along the way. Now, as the load increases, the transformer becomes too big for the pole, the transformer is then mounted on the ground. This is the second step. With growth continuing, it is then necessary to split the 4.4-kv. line into feeders. As growth continues we go to regulated feeders. By the time we have two or more regulated feeders, it then becomes necessary to house the equipment and provide substation space. Having reached the substation period, the first step would be the use of automatic reclosing switching equipment. As the number of stations increase the automatic reclosing equipment is supplemented with supervisory control from one centrally located station.

I was very much interested to note in Mr. Kelley's paper on the Commonwealth Edison System of Chicago, that they are using a similar type of distribution.

A very important consideration in the design of substations is the proper provision for future growth and extensions. The most satisfactory way to accomplish this is to design the substation on the unit plan. Additions can be made to the initial unit by the addition of one or more similar units such that in the end the station building and interior design represent a balanced electrical and architectural design. Many of you have seen a substation, very beautiful in the beginning, at the end of five or ten years having several irregular additions built around—marring its original symmetry—in order to take care of the extensions and expansions required. This, because we didn't discover or take them into account at the beginning.

Glen H. Smith: I have to thank Mr. Crawford, in his reference to my closure, for bringing out some of the questions that we considered in deciding on our distributing system. I can only say that they are questions, and that we decided them one way though often they are decided the other way. The decision as to the voltage of a circuit depends probably more on the load than it does on the size of the district served.

We find that poles are more involved with lower-voltage circuits than they are with high-voltage circuits, because of the greater number of circuits, although high-voltage circuits take more pole space per circuit.

I can't answer the question as to the effect of fluctuating railway load on our voltage regulation as the railway stations are still connected by special 13,000-volt feeders direct from the station, nothing else being connected but those stations. We have, though, heavier loads than they represent connected to the high-voltage system without any trouble. We expect that the railway stations will help rather than hinder us, by furnishing synchronous capacity to hold the 26,000-volt busses to the proper voltage level in more than the original three points.

ON THE NATURE OF CORONA LOSS[1]

(Hesselmeyer and Kostko)

Seattle, Washington, September 17, 1925

R. W. Sorensen: The peculiar curves for Fig. 1 of this paper have to be used in charting the results because a piece of tracing cloth, stretched over the end of the cathode-ray tube, must have lines, as shown, drawn on it to correct for the curvature of the tube and the distortion of the wave.

H. J. Ryan and J. S. Carroll: In the paper on The Hysteresis Character of Corona Formation, by Henline and Ryan,[2] presented a year ago at the Pasadena Convention of the Institute, the authors, in arriving at the existence of a space charge about a conductor in corona, worked at a disadvantage because they had not actually located the radial position of such space charge with respect to the conductor. During the past year two of our graduate students, Mr. Hesselmeyer and Mr. Kostko, proposed to study the radial location of the space charge by the simple plan of a concentric barrier that would limit the radial distance of the space charge from the conductor surface. They would use an isolated barrier cylinder mounted concentrically as specified in their paper; they would obtain the corresponding E–Q relation and then change the radius of the barrier and obtain the E–Q relation again. This plan would be continued over a wide range for the radius of the barrier in order to determine the manner in which the character of the E–Q relation would change with the barrier radius. The purpose of this undertaking was to find out whether the character of the E–Q relation, when barriers were used that bound the space charges to definite radial positions, would approach the character in form and area of the E–Q relation as found for widely separated parallel conductors surrounded by no barriers.

When the work was completed and this paper was prepared by the authors and studied by us, the following point of view developed: The areas in units of energy, given by the Hesselmeyer-Kostko E–Q diagrams, could be expressed in terms of the voltage and the capacitances of the conductor to the space charge and of the conductor to the grounded cylinder or neutral plane. The corresponding power would be the product of the energy by the frequency. Henline and Ryan, in their paper a year ago, had given the corresponding equation for the energy per cycle in terms of voltage and but one value of capacitance, viz., that of the conductor to the neutral plane. It was manifest that, by combining these equations, one could isolate the value of the capacitance of the conductor to the space charge.

Mr. Kostko then derived the equation for the power lost in corona using a barrier, as follows:

$$P = 4 f C (E E_0 - E_0^2) \frac{1}{\dfrac{C''}{C'} - 1} \tag{2a}$$

wherein

E, is the value of the crest voltage,
E_0, the value of the critical voltage,
C, the capacitance from conductor to neutral,
C'', the capacitance from conductor to the space charge, and
f, the frequency.

The corresponding equation given in the Pasadena paper a

1. A. I. E. E. Journal, October, 1925, p. 1068.
2. A. I. E. E. Journal September 1924, page 825.

year ago, wherein the term C'', capacitance of conductor to space charge was not used, was:

$$P = 4 f C (E^2 - E E_0) \quad (2)$$

By combining and reducing these equations the value of the capacitance of the conductor to the space charge was found to be:

$$C'' = C\left(\frac{E_0}{E} + 1\right) \quad (3)$$

If the radial distance from the conductor to the cylindrical space charge be D_r, and the radius of the conductor r, then the value of C'' will also be:

$$C'' = \frac{0.00368}{\log_{10}\left(\frac{D_r}{r}\right)} \quad (2d)$$

By combining equations (**2c**) and (**2d**)

$$\log\left(\frac{D_r}{r}\right) = \frac{0.00368}{C\left(\frac{E}{E_0} + 1\right)} \quad (2c)$$

and

$$\log D_r = \log r + \frac{0.00368}{C\left(\frac{E}{E_0} + 1\right)} \quad (2f)$$

wherein:

D_r and r are in inches

C and C'' in farads per 1000 feet of conductor.

Equation (**2f**) was applied to one of the corona loss-voltage curves[3] given by Professor Harding's Pasadena 1924 paper[4] the following locations of the space charge were obtained:

e Kv., r. m. s. swe, to neutral	D_r in inches	Kv. per inch, r. m. s. Conductor to space charge	Kv. per inch, r. m. s. Between pointed electrodes*
140	9.5	14.8	10
165	12.0	13.8	10
220	18.9	11.6	9.9
260	24.1	10.8	9.8
300	29.8	10.	9.8

*A. I. E. E. Standardization Rules, 1912.

As a check upon this understanding of the distance of the space charge from a conductor in corona the following trial was made: In front of a pointed electrode at a distance of 9.5 inches a grid of fine wires was mounted. Alternate wires were electrically connected, thus forming two groups of wires each interlaced with the other. To the groups, a 20-volt, dry-cell battery was connected through a portable galvanometer; 60-cycle alternating voltage was then applied between the pointed conductor and grounded plate and the indications of the galvanometer noted as the value of the voltage was raised. The galvanometer indicated that no current was set up through the air between the two groups of wires in the grid until the voltage was raised to an effective value of 110 kv. Thereafter the current increased at the rate of 0.1 microampere per kilovolt until the value of three microamperes was attained at 140 kv. As a slight further increase of the voltage was made, the current through the air between the grid wires rose to eight microamperes. And then, as the voltage increase was continued, there was no corresponding continuation of increase of current. This is precisely the sort of thing that should happen if the foregoing understanding of the existence and position of a space charge about a conductor in corona is correct.

The matter was tried out by another plan: The space charge was reversed while the voltage increased from the critical value E_0 to the crest value, E, in a corresponding interval $\Delta t = t - t_0$. During such interval, Δt, electrons must travel from the conductor to the location of the space charge when the potential of the conductor is negative, and vice versa when positive. When the electrode in corona is the point of a conductor, the resulting luminosities produced by the migration of the electrons as just specified might be intense enough to be visible in full darkness to or near to the radial position of the space charge. On trial, such was found to be the case.

Another reasonable conjecture in regard to action due to the space charge was encountered: Voltage was applied between a pointed conductor and a grounded metal plate. As the voltage was raised corona filled a conical space that expands from the point toward the plate through distances in relation to voltages that correspond roughly to those given in the above table. As the voltage crests occur the space charges and point potentials have the same sign, while the signs of the space charges and bound charges induced in the grounded plate as opposing electrode are opposite. The consequence is that the intensity of the electric field between the space charge and the point has been reduced and that between the space charge and plate has been correspondingly increased. The outcome must be that, as the voltage is raised, critical electric stress will be encountered in the air between the space charge and the plate beyond which the intervening air must be ionized and rendered conductive. On trial, this too was found to be the case. As the voltage is raised, the faintly luminous cone develops, attached to the point with rounded base thrust forward. Then, as the rise of the voltage continues and the growth of the cone moved its base to a position whereat it was somewhat nearer the plate, a faint pillar of light suddenly extended from the cone to the plate; the air column connecting the point to plate had been ionized and spark-over and arcing followed with slight further increase of voltage.

And so, thus far every plan that has occurred for authenticating the existence and position of the alternating space charges established and maintained about a conductor in corona due to 60-cycle voltages when tried out, has resulted in corroboration of the understanding as given.

H. S. Bates: I should like to ask Mr. Hesselmeyer if there will be any means of accurately measuring corona loss? I wish to ask also what is the best method of preventing it?

C. T. Hesselmeyer and J. K. Kostko: The experiments of Prof. Ryan and Mr. Carroll are interesting not only because they prove the existence of a space charge, but also because they suggest experimental arrangements for a quantitative study of the distribution of the space charge and the field. It is easy to set up equations theoretically determining these two elements (Poisson's equation and equation of continuity); but numerical solutions could only be obtained by reducing these general equations to simpler types, based on the results of a preliminary experimental study of the problem.

In the author's opinion the most accurate method of measuring corona losses available at present is by means of the high-voltage wattmeter developed at Stanford University and described in several Institute papers by Mr. Carroll and others.[3] In Fig. 17 of the paper the losses measured with this wattmeter are compared with the losses obtained by a very different

3. In applying these equations it should be remembered that the voltage must be taken at a value sufficiently above the critical voltage to ensure that a fixed brush pattern has been formed and the value of C is a constant as presented in the Pasadena paper.

4. *Corona Losses between Wires at Extra High Voltages*, by C. F. Harding, A. I. E. E. Journal, October, 1924, page 932.

3. *Power Measurements at High Voltages and Low Power Factors*, by J. S. Carroll, T. F. Peterson and G. R. Stray, Journal A. I. E. E., Oct. 1924, page 941.

Some Features and Improvements on the High-Voltage Wattmeter, by J. S. Carroll, Journal A. I. E. E., Sept. 1925, page 943.

method—integration of the E-Q cyclograms—and the agreement is remarkably good.

As indicated by the theory and confirmed by experiment (Fig. 8), it is possible to reduce corona loss by setting up a suitable space charge around the conductor, for instance by enclosing it in a cylinder of a small diameter; it does not seem, however, that this method is suitable for practical applications; at least in the case of a transmission line. A radical reduction of the transmission frequency would result in a reduction of corona loss (Fig. 17), in addition to many other advantages, such as better regulation, etc.

POWER DISTRIBUTION AND TELEPHONE CIRCUITS—INDUCTIVE AND PHYSICAL RELATIONS

(Trueblood and Cone)

Seattle, Washington, September 18, 1925

H. S. Phelps: Messrs. Trueblood and Cone have very ably and clearly pointed out the importance of the type of power-distribution system in the matter of inductive coordination. This importance is recognized, and as the problem is better understood, more and more attention is being given it. It seems to me, however, that they have not placed sufficient stress upon another equally important feature—namely, the characteristics of the telephone system.

The ideal arrangement, of course, would be, first, a power system without residual currents or voltages, with the conductors very close together. Such a system would be closely approached by using multi-conductor cable, where all the current was forced to return in the conductors; second, a telephone system without any impedance unbalance in the metallic circuit or admittance unbalance between the two sides of the circuit to ground. In this desirable telephone system the subscribers set should not require utilization of an unbalanced ground connection for ringing. Connecting such an instrument to the system by means of a well designed and carefully installed cable circuit to a well balanced central-office cord circuit would likewise materially improve the situation.

An ideal power system would not produce longitudinal voltage in neighboring telephone circuits, and therefore could not cause noise in the telephone system, regardless of telephone circuit unbalances. On the other hand, an ideal telephone plant would not be susceptible to induced longitudinal voltages, and therefore could not be affected by any distribution system during normal or abnormal conditions, unless the induced voltages were of a magnitude to constitute danger to life or property.

Since neither ideal system is necessary or practical, it remains to determine how far either system may depart from the ideal without placing serious limitations and burden on the other. In order to ascertain the technical facts underlying this problem, the joint Development and Research Committee of the National Electric Light Association and American Telephone and Telegraph Company has been carrying on work under one of its projects at Minneapolis for over a year.

Although many interesting and useful results have been obtained, it would be premature to attempt outlining any of these at this time. However, it is expected that an interim report will be issued in the early spring covering the major findings of this work.

The considerations outlined for coordination of the telephone circuits with a distribution system apply in the same manner to the problem of induction from a lighting system discussed in the paper by R. G. McCurdy.[1]

P. D. Jennings: I gather from reading this paper and from an informal talk with Mr. Cone that the residual higher harmonic currents are the ones that give the most trouble. I should like to ask why resonance shielding on substation ground circuits might not take care of most of this trouble. As an example, suppose in a particular substation, our oscillograph records show that the ninth and fifteenth harmonics are predominant. It occurred to me that a resonant shield might be used to resonate out the ninth and the fifteenth harmonics on the substation ground and in that way eliminate most of the trouble.

A. A. Williamson: Mr. Cone referred to the relatively greater freedom from inductive interference that is usually experienced when both the power and the telephone circuits are in cable. Cases sometimes arise, however, where interference is experienced between the two classes of circuits when they are both in cable, and such cases are usually of somewhat more than ordinary interest. A very brief reference is made to such a case in the paper and it seems to me that a few words of additional description of the conditions in that case would be interesting.

In this instance, power at 13,000 volts was supplied directly by a three-phase generator, connected in Y and with the neutral grounded, to two open-wire circuits, branching and each supplying 13,000-volt power to a substation. The power company decided to provide a tie between the two substations and concluded that in this case the tie should be of cable. The tie when installed was approximately 1.65 mi. in aerial cable, and about 0.7 mi. in underground cable. The sheath of the underground cable was, of course, well grounded, but was not connected in any way to the neutral of the generators. This cable tie paralleled in its aerial portion an aerial telephone cable.

As soon as the tie was energized, interference was noted in the telephone circuits. An investigation showed that the sheath of the aerial power cable was also grounded at intervals with driven grounds but that these grounds were of rather high resistance so that the residual charging current flowing into the cable sought ground and returned to the generating station through the low-resistance ground afforded by the sheath of the underground portion of the cable. Thus the charging current flowed through the parallel as residual current and produced interference. By installing a low-resistance ground on the sheath of the aerial portion of the power cable, at the end more remote from the underground portion, the induction was very greatly reduced. The reason for this was that with the additional ground in place, the charging current flowed through the capacity of the wires to the sheath and back over the sheath. Thus, in each part of the parallel, there was a return path for the charging current flowing out over the three-phase wires and instead of acting as a residual current, it became a balanced component. This case illustrates the effect of residual current in causing induction sometimes of serious magnitude even when both classes of circuit are in cable.

I should like also to cite very briefly a case with which I happen to have had intimate contact on the Atlantic Seaboard. This case illustrates the importance on the induction problem of unbalanced load current flowing in the ground. In this instance, a 4000-volt, three-phase, four-wire distribution system with the neutral grounded at the point of supply, paralleled in open-wire construction an aerial telephone cable. The parallel was about 8000 ft. in length; it was joint construction and at the end of the parallel more remote from the point of supply to the power system, the three-phase, four-wire circuit entered underground power cable. At that point, the neutral wire of the three-phase, four-wire system was connected to the underground cable sheath. As the sheath of the underground cable was well grounded, it could be seen that any current in the neutral due to unbalance of load between the three phases would return to the power station both by way of the neutral and by way of the ground, the division of current in the two paths being in approximately inverse proportion to the impedance of these two paths.

In this case, measurements were made of the interference on party line subscribers' circuits in the telephone cable, and approximately 900 standard noise units were found at the subscribers' receivers. Owing to the excellent cooperation of the

1. Induction from Street-Lighting Circuits, by R. G. McCurdy, A.I.E.E. Journal, Vol. XLIV, October, 1925, p. 1088.

power company in this case, it was possible during the investigation to disconnect temporarily the power cable from the aerial portion. When this was done, the path for the unbalanced load current to return through the ground, no longer existed. Under this condition the induction was reduced to about one-third of its former value.

This case seems to illustrate very well the effect of unbalanced load current when it can return through the ground. The use of power cable with the sheath connected to the neutral wire is only one of the ways in which a path may be provided for unbalanced load current to return through the ground. Whenever the neutral wire of a three-phase four-wire system is grounded at several points, this same opportunity exists and experience has indicated that it is usually one of the most important features from an induction standpoint.

K. L. Wilkinson: In practically all cases telephone subscribers are users of electric light and power service. Therefore, the companies, in order to serve these customers in distribution areas, must of necessity have their overhead lines in close proximity to each other. The problems arising therefrom are mutual ones since they involve the rendering of both services to these common customers in a safe, adequate and economical manner. It seems to be now generally appreciated that these problems require cooperative consideration by the two utilities in order to be successfully solved. The advantages of this cooperative treatment have generally been recognized throughout the country, and the splendid cooperation between the operating utilities in the field is producing most satisfactory results.

Now, in order that these individual efforts in the field may be most successful, it is desirable that all parts of the country know what is going on in all other parts of the country and be in a position to have made available to them all of the data and information which would shed any useful light on the problem. To this end, some four years ago there was organized the Joint General Committee of the National Electric Light Association, and the Bell Telephone System. This Committee was to investigate the physical relations between electric supply lines and communication lines, and to develop principles and practises for the guidance of the operating companies in solving their day-by-day problems.

The Joint General Committee has at its disposal all the operating experience of the country and has, as you know, published *Principles and Practises for Inductive Coordination of Supply and Communication Systems.*

The principles which have been developed are nothing new; they are based on the operating experience in their day-by-day work in coordination of the two systems.

One of the most important, I think, is the principle of cooperation and the advance notice. I thought of that particularly when Mr. Heinze mentioned the growth and development of the power systems in the distribution areas, the increasing load density and of the fact that nearly everybody now has a telephone, and every telephone must be a part of a system that operates throughout the United States, so that any one telephone in any one part of the country can be connected with any other telephone in the system.

If we are going to have the best and most economical power system to supply the people with electric light and power, and if we are to achieve the ideal of universal communication throughout the country, it is absolutely essential that locally and nationally we establish and maintain the closest contact between the two utilities in order that the public may obtain the fullest benefits of all of our engineering knowledge and experience.

The Joint General Committee, in approaching the problem, established one thing clearly and that was that each party should be the judge of his own service requirements and what was necessary to serve his customers. Next to that was the duty of coordination; that is, each party should so conduct his business as to be less productive of adverse influence on the other system; and, the system should be as free as practicable from things which would make it capable of being adversely affected.

I think that if we bear these major thoughts in mind,—first, that each is the judge of his own service requirements, and second, that we have a mutual duty toward the public to see that they get safe, adequate and economical service,—then the necessity of planning well in advance so that the situation does not get out of hand will be fully appreciated and we shall be promoting the best interests of the public in getting these two necessary services.

F. O. McMillan: Would it not be advisable to include in this paper under the three-phase transformer connections, some reference to both the primary and secondary winding connections, because of the fact that the third-harmonic magnetizing current and all multiples of the third harmonic in Y-delta-connected transformers are very nicely cared for when the delta connection is used on either side of the transformer?

S. B. Hood: In the paper I note, in the tabulation of the relative ease of coordination of the different systems, that almost without exception, the power system which is easiest to coordinate is the very system which the power man does not want to use.

Now that means that we must have a cooperative spirit of give and take. At some place in the list is the system which is just as good for the telephone man as for the power man. Just where it is, I don't know. I don't think it has ever been discovered, but we certainly have to work in a true cooperative spirit toward that end.

M. T. Crawford: Mr. Cone refers to the possibility of a slight ground which persists for some length of time as being a very serious source of interference when it occurs on the primary system.

I believe that practical experience will bear me out that on a grounded-neutral primary system it is almost impossible for a slight ground to persist for any great length of time. The ground on the grounded-neutral system is a short circuit and very soon develops into something that will trip the switch out. That would be an argument in favor of the grounded-neutral system as being superior from the point of telephone interference.

I should like to ask Mr. Cone what he considers the principal objection to raising somewhat the 5000-volt limitation which is at present observed in connection with joint-pole construction of light-and-power and communication circuits. This, of course, is an old question, but it seems today to assume a new aspect inasmuch as there is here evident such a willingness to cooperate. Perhaps the difficulties of joint-pole construction on voltages over 5000 have been where the distribution work of the light and power companies was not planned far enough in advance to take into account the telephone company problem.

The Puget Sound Power and Light Company now operates on a part of its system a commercial telephone system, which was taken over in connection with the purchase of a smaller company. On this system we have 6600-volt primary distribution on our own poles in combination with our own telephone service lines. We have been able to live very well with ourselves under such conditions.

L. J. Corbett: I wish to second Mr. Hood's remarks in regard to cooperation in spite of the suggestion which has been made that a wave of propaganda is upon us.

I have observed that the telephone men have studied the theoretical part of power transmission and distribution rather thoroughly. But very few power men study the telephone problems thoroughly. If we did and suggested to the telephone companies how to operate their systems, it might be taken in the same spirit as that in which the power men receive suggestions from the telephone men as to how they might operate their systems.

The ideal manner of handling the inductive-coordination problem would be realized if the same interests owned both the communication system and the power system. If this were true

they would be compelled to get together and determine the accurate economic solution in each case.

In California we act under the California Railroad Commission. The order of the commission is a state law, and under that law we are "required to cooperate." We find that this cooperation really works both ways. It is not always merely doing that which is requested by the telephone company; we do a little telephone engineering ourselves, although not in a very aggressive way. When the telephone company suggests coordinating measures, as a rule we put them in when it is possible without unreasonable expense.

If, from our standpoint, they do not appear reasonable, or if some construction or operating difficulty is involved, or a higher unjustifiable expense is indicated, we raise the question as to whether or not the benefits to be gained by these measures are worth the expense and trouble involved. When such communications reach telephone company officials, the requests are usually modified or dropped.

The beauty of the California law is that public interest comes first, and the cost of any of these coordinating measures is reflected in the rate. In this manner the public is the final unifying agent or manager and the holder of the purse-strings.

F. H. Mayer: Mr. Cone raised some objection to the grounding of the neutral return on 4-kv. distribution systems. It is the practise of the Southern California Edison Company to ground the neutral at numerous points throughout the distribution system to enable the secondary voltage to remain somewhere near a safe value should the return cable become broken. The driven pipes will tend to span the gap and thus prevent the Y connection from straightening out to a straight delta connection. If the loads on the different phases are carefully balanced there ought not be any communication disturbances.

H. M. Trueblood: I am sure we can all endorse the attitude expressed in Mr. Phelps' discussion, namely, that the solution of the problem consists essentially in finding the degree to which ideal systems must be approximated.

Mr. Phelps' reference to the joint investigation at Minneapolis should, I feel, include mention of the Northern States Power Company and the Northwestern Bell Telephone Company as participants. The progress which has been made in that work is due in no small degree to the effective cooperation and assistance of these two companies.

As regards the suggestion that the paper does not lay sufficient stress on the characteristics of the telephone system, I wish to say that there is no desire to ignore this phase of the problem. The paper has been presented as one of a group dealing with various aspects of power distribution and, as such, it does not purport to discuss telephone-system characteristics, except incidentally.

With reference to Mr. Jennings' inquiry, I know of at least one case in which the measure which I believe he has in mind was applied successfully. In this instance, there were two harmonics to be taken care of, the 15th and the 33rd, and two antiresonant elements, each consisting of a condenser and an inductance in parallel, tuned respectively to the frequencies of these two harmonics. They were connected in series between the neutral of a 13,000-volt generator and a grid resistance of low value, the other terminal of which was grounded. The exposure involved was about 3 mi. long at a separation of some 30 ft. I have been informed that effective reductions were obtained in the noise, previously quite severe, and that the arrangement has proved satisfactory from a power-operating standpoint.

Mr. McMillan refers to the omission of reference to the effects of delta windings. Because of the rather extensive ground covered in Table I, it was necessary to simplify the table and to make some selection among the different features that might be included. Of course, delta windings on transformers do affect the magnitudes of the triple-harmonic voltages and currents that appear on the lines; but this effect may be either to increase or to diminish the magnitudes of the line residuals of these frequencies, depending upon the locations of the transformers concerned and the conditions of grounding. Of the systems summarized in the table, those presenting the greatest difficulties in coordination are ones in which the load currents are more important than excitation currents, and, of course, the transformer connections are immaterial, so far as load currents are concerned.

Mr. Hood and others have remarked that the distribution systems classified in the paper as presenting the greatest facility of coordination are not those which a power company would ordinarily adopt if nothing more than the distribution of power were involved. Without attempting to pass judgment on the relative merits of different systems from the latter standpoint, I believe we should not be surprised that a conflict of this character is found to exist. This is an essential feature of the situation with which we are confronted at the present time. In fact, we have an inductive-coordination problem largely because types of systems which are deemed advantageous from one standpoint may not be so from the other. Mr. Hood's inference from the situation to which he refers is substantially the same as that arrived at by Mr. Phelps, and I find no difficulty in concurring in it.

Mr. Hood has referred to the use of multiple grounds on the neutral as a stabilization proposition. While stabilization may be the principal purpose in using the multiple-grounded neutral, it is unfortunately true that this does not prevent the setting up of residual load currents.

In his remarks applying to Mr. McCurdy's paper, as well as to that by Mr. Cone and myself, Mr. Heinze refers to the question of cooperation between the telephone company and the other electric utilities. It is true that most telephone engineers who have had to do with the inductive-coordination problem keep prominently before them the idea of cooperation. That is because it appears to us that no other method of approach can be successful. While this is more nearly self-evident now than it was some years ago, it is so important that one feels justified in laying stress upon the idea. The same thought has been expressed more than once by power engineers in the discussion of these papers.

Mr. Heinze asks how far the telephone company will go in this cooperative endeavor. As to the general spirit and attitude of the Bell System, I will merely remind you that for a number of years it has gone to considerable trouble and expense to adapt itself to circumstances which have arisen because of situations of proximity between its circuits and power circuits. That this willingness to cooperate in the fullest way will be maintained in the future seems to be sufficiently evidenced by the adoption of principles and practises by the Bell System and the N. E. L. A., under which cases are now being handled generally throughout the country, and by the undertaking of a joint research investigation to determine the fundamental physical and engineering factors which enter into the inductive-coordination problem. The work at Minneapolis is one project in this general research program, and other projects are under way in different parts of the country. As to division of cost, it must be recognized that after the correct engineering solution of a given case has been found, the question of an equitable division of the expenditure necessary to put it into effect will arise. This phase of the problem has so many ramifications that any attempt to summarize it here might be misleading, and a comprehensive discussion would carry us much beyond the field with which the paper is concerned.

In conclusion, I wish to make it clear that Mr. Cone and myself have attempted nothing more than to analyze the problem in a preliminary way without going into detail, and to bring out the technical facts known to us as we see them. Mr. McCurdy, I am sure, would agree with this attitude.

D. I. Cone: Mr. Crawford spoke of the interference that arises from accidental grounding of one phase wire. On a three-wire system normally isolated from ground, such conditions may

persist for days at a time, or longer. This can be prevented by suitable maintenance measures. On the other hand with the grounded-neutral system the tendency is for such accidental contacts to develop into short circuits and to operate the circuit breakers. From the discussion by Messrs. Crawford and Cunningham it is evident that the local conditions immediately surrounding an accidental ground contact cause great variations in contact resistance and resulting ground current.

Mr. Crawford has raised the question of joint use at higher voltages than has been customary in the past. Many of you are doubtless aware that the subject of conditions of joint use is under active study by the Joint General Committee of the N. E. L. A. and the Bell Telephone System. We do, of course, recognize that there are some special cases where joint use of poles at higher voltages is the best engineering solution to meet the conditions of a particular problem and in such cases joint use is being approved.

Mr. Crawford also stated that his company had lately acquired a combination power and telephone distribution system with the power lines operating at 6600 volts. Our experience has not been encouraging as to the conditions of noise and hazard that obtain in such circumstances.

There are, of course, differences of opinion in respect to the question of protection from the hazards of power distribution. I wish to suggest, first, that higher voltages are ordinarily employed in distribution for longer distances and larger loads and, second, that this inevitably means either extraordinary measures to prevent hazard and impairment of service or else lowered standards. It is our view that advance planning will enable us to avoid to a great extent the necessity of joint use at the higher voltages. Meanwhile, any specific situation that arises we are more than ready to consider.

Mr. Corbett has described the working out of cooperative consideration of specific cases in California. As he states, the best results are obtained when the reactions of proposed measures are thoroughly considered by both parties. Suggestions arising from the study of these problems by the power engineers are cordially welcomed. I think it fair to say that the working together in California is not merely a matter of compliance with regulations but a realization that it is the rational way for the power and communication utilities to solve these problems. Mr. Mayer's discussion brings out the fact that there are conflicts to be adjusted between the requirements of the communication and power distributions and that the degree of detriment from multiple grounding depends upon several factors in the layout of the systems. Mr. Mayer's point about the use of multiple grounds on the primary neutral for stabilization has also been brought out by Mr. Hood. While recognizing that accurate balance of loads might prevent detrimental induction in communication circuits so long as all phases are present, we must not overlook the facts that setting up and continuously maintaining such close balance is not a simple matter and that exposures often occur where only one- or two-phase wires are involved.

OPPORTUNITIES AND PROBLEMS IN THE ELECTRIC DISTRIBUTION SYSTEM[1]

(Blake)

Seattle, Washington, September 18, 1925

C. E. Carey: I wish to discuss one or two details in Mr. Blake's paper. He mentions primarily the single-pole protective unit. He goes into detail and attempts to establish the justification of the multiplicity of parts. However, the question of single-phase or single-pole units cannot be separated from the whole network. Personally, I believe that the multiple unit is the real solution. We have seen that there are certain state laws requiring that we open the entire circuit, rather than allow an unbalance on the networks and produce inductive interference. It is much better, I believe, to clear the entire trouble as quickly as possible rather than take out one phase at a time. The three-pole unit will not occupy as much space in the manhole as three single-pole units. The automatic a-c. network protector is a device which does everything you can expect it to do. It is designed to go into the standard 35-in. manhole cover. The covers of the units are of aluminum, are light and can be handled by one man. Furthermore, if inspection is to be made of these devices the time consumed will be less with three-pole units than with three single-pole units.

In regard to the translator, I believe, that anything we put in to complicate the network is defeating the purpose of the a-c. system. The whole thing resolves itself back into continuity of service, simplicity and low cost, and the only way we can arrive at that service with a reasonable cost is to trim it down to just the bare necessities.

Practically everyone will agree that if we had it to do over again, we would never put in a d-c. network. We have it, but what are we going to do with it? If we attempt to change to an a-c. network we are confronted with the cost of changing over the customer's equipment, which will be so high in some cases that the interest and other fixed charges on that additional cost will more than carry the high losses in the d-c. network. However, one solution is being used to bring the economics of the d-c. very close to those of the a-c. network, the use of the automatic substation. The automatic substation gives primarily the same type of distribution as the a-c. system; that is, high voltages to the converting stations and low-voltage for distribution. The automatic substation is reliable and economical. A real analysis of the problem will often show that it is better to hold to the d-c. network, remove the concentrated manually operated stations, and distribute that conversion power over a network to a large number of small conversion stations, approaching extremely close to the transformers on the a-c. network in losses and other factors which come into the distribution problem.

Henry Richter: In considering a-c. secondary networks, it is well to recognize that the network systems mentioned by the United Electric Light and Power Co. as used in New York City—and also those in New Orleans—use triple-pole automatic network units exclusively, and that similar systems and network units will shortly be in operation in Dallas, Memphis, Knoxville, and Atlanta. Minneapolis will install these units as the load grows, preparatory to forming a network. These comprise all the companies that have completed or started to construct a network like that of Fig. 2, using automatic network units.

In practically none of the installations in these cities, where space might permit single-pole units to be installed, has it been necessary to add to the dimensions of new manholes in order to accommodate the triple-pole network unit; or to construct new manholes, or enlarge old ones, due to any extra space required because single-pole units were not available; or even to take up space in an existing vault that could be ill spared. These networks are considered justifiable only in heavily loaded areas where the loads are too great to be supplied in the single-phase manner. Three-phase transformer banks are therefore the rule, ranging in size from three 25-kv-a. single-phase transformers up to three 100-kv-a. transformers. The manholes and building vaults to accommodate such banks, to allow for growth of load, to ensure no excessive temperatures, and to permit proper racking and maintenance of cables, must be of such size that there is no lack of wall space for a triple-pole network unit. It is customary to locate this unit on the wall opposite that along which the three transformers are placed, and close to a corner of the manhole. In existing manholes having three-phase banks formerly part of a radial primary and secondary system, the triple-pole network units can usually

1. Abridged in A. I. E. E. Journal, December, 1925, p. 1355. Complete copies in pamphlet form only.

be put into the space formerly occupied by the large secondary junction boxes. In most cases, this space is not otherwise useful, for the network systems employing these automatic network units are so simple that nothing else is necessary in the manhole besides the transformers with or without small reactors, the cables and the network unit. Further, it is an erroneous idea that single-pole network units, particularly in a submersible housing, can be made so tiny that they can be installed in any odd corners of a manhole. The desirability of giving them proper maintenance makes such procedure far from advisable even if they were so small.

If it is desired to have the leads to the secondary mains leave the triple-pole network unit horizontally, to either side, it is extremely simple to provide a small terminal box where the outgoing leads emerge from the top of the submersible housing. This small box can have wiping nipples mounted horizontally at either side. The extra bend in the cable is thus eliminated. However, in none of the cities enumerated has this been necessary. Seven and a half feet is an average height for these transformer manholes as determined by good subway construction practise and even with a triple-pole network unit for a bank of three 100-kv-a. transformers there is no cramping of cables entering and leaving the housing.

When the triple-pole network unit was being designed, it was recognized that the submersible housing must pass through a certain minimum-size manhole opening. A country-wide survey was made and it was learned that the great majority of companies have adopted 35-in. diameter round as the smallest opening for transformer manholes in existing or contemplated construction. Apparently this minimum was governed by the dimensions of 100-kv-a. single-phase subway transformers. Accordingly the triple-pole units of all sizes were designed to pass through a 35 in. diameter round opening. In none of the six network cities mentioned, and together they are typical of all other cities, will it be necessary to rebuild the opening of any manhole to permit the unit to pass through; and careful investigation shows that in none of the cities where three-phase networks are being considered for the future will there be any difficulty in this regard.

If it becomes necessary to rack cables along the wall back of the network unit, it is just as easy to mount the triple-pole unit on a pipe framework braced to the wall as for the single-pole unit, since the two types are not very different in depth. However, just as with junction boxes, subway oil-circuit breakers and such apparatus, electric service companies do not consider this good practise in manholes. In only one case has a company mounted on a transformer tank a piece of auxiliary apparatus of such size as a single-pole network unit might be, and there the conditions are unlike those anywhere else in the country. In general, the place for such equipment is against a wall.

Where subsurface conditions make it impossible to build a manhole for three transformers at any particular location in the street on a main thoroughfare, three solutions have been found to be applicable: (1) obtain a vault in the basement of a building; (2) install a manhole under the sidewalk, or (3) locate the manhole in the street as close to the desired location as possible. In almost no case has it been impossible to use one of these methods. Where the third method must be employed, the distance from the most desirable location is usually so short that the cost of the extra length of duct line is small compared with the extra cost of three smaller manholes over one larger one. It is also doubtful whether city authorities will permit subsurface obstruction at three neighboring points.

The triple-pole network unit for manholes is constructed with a window of heavy, wired glass, amply strong, in the cover; this makes inspection of the principle parts easier than by taking off the cover of a single-pole unit. If it is necessary to get at the parts inside, the time to remove the few extra bolts or lugs holding the cover on the triple-pole unit is negligible. The aluminum cover of the triple pole unit can be handled by one man without difficulty.

The design of the single-pole unit to permit easy removal of the panel from the housing when it is desired to make repairs at the shop follows the identical idea that is incorporated in the triple-pole network unit design. Similarly, right from the start, fuses have been installed on the panel of the triple-pole unit, in series with the outgoing leads, to make a separate fuse box unnecessary. These last two points, therefore, do not apply exclusively to single-pole units.

The paper claims that the single-pole unit conforms with the method of single-pole switching inherited from the radial system of distribution. In a properly designed three-phase network system single-pole switching is no longer necessary and may be abandoned. In a radial system it is better to have some light than no light, when trouble occurs on a feeder, and hence the value of single-pole switching. Networks are designed so that in no case will trouble on any feeder cause interruption of any service fed from the secondary network. Among such troubles there must always be included the putting out of service of all three conductors of a feeder, either by phase-to-phase short circuit in a three-conductor cable, or, where three single-conductor primary cables are in the same duct, by the melting down of all the conductors by a severe fault to ground on one of them. It may even be necessary to provide for the possibility of a manhole fire taking two feeders out of service simultaneously. Thus, there is no necessity in complicating the system to get the insurance that goes with keeping two of the phases in service when the third goes out. One large company even plans to use three-phase regulators on three-phase feeders serving an important network, and some are thinking of using triple-pole oil-circuit breakers at the station and three-phase distribution transformers where these can be passed through the existing manhole openings.

The paper overemphasizes the importance of manhole installations. While the difficult conditions encountered in manholes must be met and are being met, it should be remembered that of a total of over 600 triple-pole network units that will be in operation by the end of this year, less than one third will be in manholes.

Three single-pole units have three operating mechanisms in place of one for the triple-pole unit, and this means more parts to maintain. Three units together have more surface to gasket than a triple-pole unit, which gives more chance for water to leak in with any given type of construction. Three units also occupy a greater total space in the manhole, and every cubic foot is valuable. When the design of automatic network units was first under consideration, all these factors were weighed and the single-pole type was abandoned as inferior to the triple-pole type.

The simplest method of ensuring stable operation of regulators on feeders operating in parallel on a network[2] does not require any extra apparatus such as the transformers T and reactors X of Fig. 3. It employs only a transfer switch, corresponding to switch S for each feeder. This scheme was given a thorough test on the network system of the United Electric Light and Power Company, where it originated, and was shown to be entirely satisfactory.

One of the greatest problems in connection with secondary networks is the type of combined light and power secondary system to employ. Mr. Parker has blazed the trail in an effort to devise some scheme whereby the advantages of the combined system may be obtained and the disadvantages of the star connection avoided. It cannot be too strongly urged that others follow in his steps. However, it must be pointed out that the translator scheme may introduce disadvantages that outweigh those of the simple four-wire, star system, and these

2. Described in the *Electric Journal*, July, 1925.

disadvantages may so handicap the development of the network idea as to result in a loss to all concerned.

In the star system of Fig. 4 the only voltage unbalance at the motor terminals is caused by unbalance of load in the secondary mains due to varying sizes of the loads as encountered along the street. This unbalance may be reduced to a negligible amount by care in connecting two-wire and three-wire services on alternate phases. From the analysis of the translator scheme it is evident that it may easily result in voltage unbalances of at least 10 per cent at the motor terminals. For the same per cent voltage unbalance on a motor as per cent voltage reduction, both the heating and starting torque are affected to a worse degree in the case of the unbalance. Hence the effect on motors would be worse with the translator scheme than by operating them at 199 volts on a 115/199-volt star-connected secondary.

Adding extra transformers on other phases to obtain a better balance of voltage where power loads are frequent not only increases the number of transformers on the system, but also calls for larger or more manholes to house them. This would materially cut down the savings in transformer capacity gained by the diversity that networking makes possible.

Where the 115/199-volt star-connected secondary system is employed it has been necessary to use auto-transformers on not more than 15 to 20 per cent of the motors connected to the system in order to supply satisfactory voltage. On the basis of power load equal to half the lighting load these auto-transformers represent less than 7 per cent of the capacity of the secondary system. If the translators, equivalent in capacity to the total capacity of the secondary system, cause an increase of investment averaging 10 per cent of the entire distribution system cost, the auto-transformers necessary to ensure satisfactory operation of motors on a star system involve an increase in investment of less than 0.7 per cent.

The unbalance of current for the case of power load half the lighting load requires that the wire carrying the maximum current in the translator system use about 60 per cent more copper than for the star system. It would be highly inadvisable to proportion the size of the three-phase wires in the translator scheme according to the loads in those wires, because the sizes would have to be changed from block to block all over the system, and this would complicate the system even more than by adding the translators. Hence all secondary wires would be as heavy as the largest one, and this might mean a 60 per cent increase in the total amount of secondary copper required. Where 500,000-cir. mil copper is taken as the largest size, the extra copper would in many cases require a second main and duct. To these extra costs must be added those of the translators, value of manhole space they would occupy, and losses in secondaries and translators. Even the seven-wire, separate-light-and-power secondary system would not cost more and would be simpler. The increase in cost due to all these items might easily overcome any saving gained by combining power and light mains and defeat the very purpose of the translator scheme.

If the electric service companies want to inconvenience the fewest number of customers using a star-connected system, they will adopt the 115/199-volt three-phase system, as only the polyphase motor users will be affected. In the few cases where tests show insufficient voltage, the simple auto-transformers can be employed to boost the voltage. In Memphis, a 115/199-volt system of this kind has been in operation for over ten years and the customers are entirely satisfied. In Rochester, for several years, light and power loads in large buildings downtown have been supplied by 120/208-volt transformer banks in the basements and, even though motors up to 40 h. p. are connected at the end of long risers and no auto-transformers are employed, the customers praise the service.

It must be recognized that for most systems an a-c. network system, even though fed at 13,200 volts is just a little less than half the annual cost of a d-c. system and hardly less than 80 per cent of the cost of an a-c. radial system. These ratios have been checked independently by the engineers of five large systems. Hence, we would be deceiving ourselves as to the economic value of the translator scheme for it introduces such elements of additional cost as would wipe out the balance now in favor of a-c. networks.

The control of multiple street lamps or pole-mounting, constant-current transformers supplying series street lamps, by means of carrier current over the primary feeders, will represent a great step ahead. One company has tried out such a system, but the operation has been faulty and the relay units on the poles are of such nature as to be relatively expensive. The sender at the substation is also complicated. Another company has developed a simpler form of relay unit, and tests of a number of these, equivalent to at least a full year's service, have proved them satisfactory. This relay unit is compact, substantial and inexpensive. The sender unit is also simple and strongly built.

M. T. Crawford: Mr. Blake's paper refers to a method shown in Fig. 5 of which the title is "New Connection of Induction Regulator Circuits to Eliminate Circulating Currents." I think I am correct in stating this connection has been used recently by our company in our new Union Street substation and has proved very successful in regulating 4500-volt feeders in a multiple-feed network. One practical point in connection with it has been that some means has been found desirable to automatically disconnect the regulator control circuit on low voltage, so that regulators will not assume, during system trouble, different positions after fluctuations. I mean by that if a short circuit comes on the transmission network, and the voltage of the system as a whole oscillates back and forth, perhaps reaching very low values for brief moments, there is a tendency for the regulators to attempt to follow these voltage variations up and down. By the time matters have settled down again, some of the regulators are in one position and some in another, due to their slightly different characteristics. That has resulted at times in tripping out of network switches on the underground distribution system due to reverse flow of power for brief periods from one feeder into another where the voltage conditions were slightly different. By the simple expedient of providing a low-voltage release on the regulator control circuit, this trouble has been eliminated. The operator at the substation can reset the control circuit after the system has quieted down to normal.

The translator referred to is a very clever development. The Puget Sound Power and Light Company's underground distribution system employs single-phase, three-wire mains for lighting and alternate blocks with longitudinal alleys are placed on alternate phases, so the first alley is on one phase, the second alley on another, and so on. By that method the phases are relatively well balanced at the substation. In places, we have recently installed a fourth wire paralleling the single-phase, three-phase mains to provide small polyphase service. The result has been three-phase, four-wire mains in each alley similar to the ones referred to by Mr. Blake, and the respective alleys in the same phase relation as those shown in his diagram.

The translator, therefore, in our case offers something to look forward to as a possibility of permitting interconnection of the three sets of secondary mains for purposes of phase balancing or load protection if it should be found desirable. However, the addition of apparatus is always to be very closely scrutinized, and its necessity must be proven before it is added, as the simpler a system is, the better the service will always be.

A. H. Kehoe (communicated after adjournment): Regarding Mr. Blake's discussion of single-pole versus three-pole a-c. subway network switches I consider the proper switch to use is the one which will give minimum cost over an extended period. The cost of revising a few existing locations will be negligible on the total installation cost. Tripping and closing

elements in these switches represent a major item of cost and single-pole units will nearly triple this cost for each installation. Space, that is, cubical contents, naturally will be less in a three-pole unit than in three single units. These conditions seem to make the three-pole unit the one to be adopted generally. However, I do not favor certain of the existing three-pole switches of the so-called "battleship" construction. If the principal installation advantages set up by Mr. Blake for single-pole switches be used as specifications for three-pole switches, none of the latter's many advantages need be considered except the greatly reduced cost.

Under operating advantages there are several references to separating the phases either in the physical location or for operation of the transformers. I believe this is a case of confusing what *can* be done with what *is likely* to be done. It is possible to separate phases in three transformer vaults but it is probable that one vault three times as long will be cheaper and better if polyphase load is to be supplied. The system of polyphase secondary distribution is primarily for better universal utilization of electric service, as methods of balancing are now successful without it. However, that balanced polyphase loads are desirable at all points on a system, is a design axiom. All progress up to this time points to polyphase rather than single-phase distribution transformers for ultimate use. If the standard three-wire, single-phase system is taken as analogous to the polyphase system, it is evident that two single-phase, two-wire transformers could be placed in separate transformer vaults supplying a three-wire system. This is not likely to be found, however, in standard practise as all the capacity is found in one unit and a vault is built to take this larger unit, as this design gives minimum cost. I believe similar conditions will hold as the polyphase system develops.

Concerning the operating situation with radial distribution, the single-pole substation switches had economical advantages which could be charged to reliability. Since, in network distribution, there must be, and is always, sufficient reserve on each phase to allow for a failure of that phase, in each locality where it exists it is certain that the remaining phases will have sufficient reserve capacity to be eliminated in case of fault. Such operation does not have any effect upon service which can be equated against the increased cost, when the money, if necessary, could be expended to obtain an increased reserve upon all phases so that the particular phase in trouble would benefit by having a greater reserve. I doubt whether single-pole network switches are proper even with those systems already operating with three single-pole switches on four-wire, 4000-volt service, as new load will cause a higher voltage supply to be used than 4000 volts. It is possible to superimpose the new load on to the existing system and avoid the double transformation which is otherwise required.

Mr. Blake describes a method of cross-current compensation as the "most promising." It is, however, neither simpler nor easier of installation than others now in use. The several such connections should be given consideration before applying a definite arrangement to a particular system. The method described makes constant current and power factor the major considerations, while constant service voltage becomes a secondary one. Constant and correct service voltage is one of the most important elements in the business. While the network insures reliability and better voltage regulation than on radial systems yet this latter should not be compromised unnecessarily. It seems to me to be preferable to design the system for proper balance of load and have the regulating equipment give proper voltage under all conditions. The connection proposed does the opposite. Applying such a connection to a number of long feeders on an extended network makes other connections preferable due to the voltage variation under the ordinary load shifting.

It should be noted that a distribution network does not simulate a bus in respect to voltage or to concentration of load as indicated in Fig. 3 of the paper.

I fail to find in the translator description any reference to the use of this connection on certain distribution transformer secondaries to join and supply the different mains. If such a device ever has a practical application I believe it will be necessary to make it up in such a form, rather than as an auto-transformer, owing to cost and losses involved. Mr. Blake's statement that each section of secondary mains on a Y-connected system is not likely to be well balanced is not in accord with the purpose of adopting polyphase distribution. In some existing installations a certain amount of unbalance may exist due to the utilization having been designed for three-wire, single-phase service, but new installations are easily balanced and it is only in districts where growth of loads occur that any considerable amount of three-phase, four-wire mains are likely to be installed.

D. K. Blake: Mr. Carey questions the application of the single-pole switch. Mr. Richter's discussion also differed as to the application of the single-pole switch. It is recognized that the objection to the multiplicity of units for maintenance is valid. It is also recognized that a number of large companies will be able to utilize building and sidewalk space and, therefore, for these places the triple-pole switch is preferable. In the synopsis of the paper is this statement: "The circumstances which make single-pole switching preferable are outlined." It was my impression that there was a similar statement in the text, but on reading it over I notice there is not, and, therefore, some wrong conclusions might be drawn because of this omission. In his discussion Mr. Richter seemed to deny that these circumstances exist at all. He mentioned the cities where the large switches are being used. I agree with him that the triple-pole switch is preferable in these cities with one exception. Mr. Richter's references to the design of the switches indicates he misunderstood the paper. No exclusive features are claimed. To include all of these features in a triple-pole switch presents serious difficulties which are expensive to overcome. The operating advantages of single-pole switching may be questionable. Some engineers believe it desirable.

Mr. Richter mentions that the transfer switch shown in the *Electric Journal*, July 1925, corresponds to switch S shown in Fig. 3 of my paper. Switch S is a single-pole auxiliary switch whereas the transfer switch consists of four auxiliary switches or else one auxiliary switch to control an electrically operated double-pole double-throw switch. The cross-connected scheme is not as simple in its operation. All regulators are not adjusted at the same time according to the amount of circulating current passing through them but adjustment is obtained in a sequence. Mr. Kehoe's statement that the proposed connection does not "give proper voltage under all conditions" is not clear to the author. The line-drop compensator in each feeder maintains constant voltage at the load center with varying load. The impedances of the feeders may be different, some feeders may be long and some short. The proposed connection, by substituting a phase shifter at T, can also be used with three-phase regulators which is not true of other connections now in use.

I want to thank Mr. Crawford for telling us of his experience with the new regulator connection. We shall have to learn something about the operation of this connection on the systems where we use the sensitive reverse-power relay. I am glad to learn that Mr. Crawford has found a simple way of correcting the trouble.

It is not evident to the author why the translator system "may easily result in voltage unbalances of at least 10 per cent at the motor terminals." The translator system is simply the tying together of four-wire combined light-and-power mains which are supplied by delta-connected transformers. The unbalance on these mains is due to the lighting load on one phase and since this is limited to 3 per cent regulation that is also the extent of the unbalance on a 230-volt circuit. Heavy power loads are usually supplied with individual transformer banks and, there-

fore, it is not evident why larger or more manholes are necessary for this purpose on the translator system.

The translator system may be used with single-conductor cable with two of the phase wires larger than the third—just as is done in radial practise. These sizes would not have to be changed from block to block but would be uniform over the system. The case of power load equaling half the lighting load required that the wire carrying the maximum current in the translator system use about 34 per cent more copper than for the star system instead of 60 per cent as given by Mr. Richter.

Mr. Kehoe refers to a scheme using transformer secondaries. Such a connection is shown in Fig. 1, herewith, utilizing four

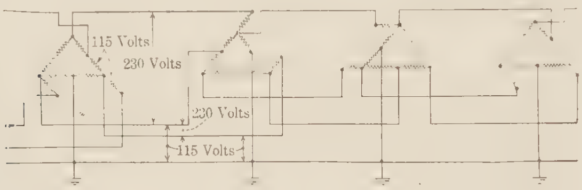

FIG. 1

standard distribution transformers. The main objection to this system is that it is tied up with the primary feeder making it necessary to provide two triple-pole network switches for protection. The translator is independent of the primary voltage. The fourth transformer is greater in kv-a. rating than the translator and very much more expensive in case of 13,200-volt or 11,000-volt primaries. The fourth transformer should be located in the same manhole with the other three while the translator may be located where convenient. Part of the lighting load is supplied from open-delta connections.

DISTRIBUTION TO SUPPLY INCREASING LOAD DENSITIES[1]

(CRAWFORD)

SEATTLE, WASHINGTON, SEPTEMBER 18, 1925

C. A. Heinze: Mr. Crawford assumes as an ultimate load density in his residential areas approximately 6250 kw. per sq. mi. He has used some figures that apply apparently to Seattle, which possibly may not apply to other cities. The number of houses per block, and the number of blocks per square mile — those are local conditions. The ratio of apartment houses and flats to single residences determines the load density for residential consumers. Studies of the conditions as they exist in Los Angeles show that it is reasonable to expect future load densities of 2500 kw. per sq. mi. for single residences, 6000 kw. per sq. mi. for flats and 19,000 kw. per sq. mi. for apartment houses. The actual load density in any square mile will be determined by the ratio between the different classes.

A few years ago the Commonwealth Edison Company of Chicago had already experienced in the Loop district a load density of 75,000 kw. per sq. mi., and was preparing for a future load density in this same area of 200,000 kw. per sq. mi.

The great majority of papers presented at this convention have to do with Y-connecting the present 2300-volt systems in order to get a higher feeder voltage. Personally I think that we are wrong in stopping at this voltage. We should go higher. While some authors have intimated in their papers that if they were to start over they would probably adopt higher voltages, it seems to me the sooner we adopt the highest practical voltage considering future load densities, the easier our future distribution problems are going to be. Certainly we do not want our systems growing larger and larger with the lower voltages, and then reach a time when we have to change to a higher voltage. Why not do the changing at the time when the system is small?

One thought that seemed to run through all the papers is that each of the authors in turn said he has a system plan. Certainly that is a big step in the right direction. The trouble in the old days was that we did not have a system plan.

Having a system plan, and realizing the enormous load densities of the future, we should build today that proportion of the ultimate plan which will give us maximum economies.

It should be realized that when a 2300-volt delta-connected system is Y-connected, we have then reached the ultimate change that can be made in that particular system. On the other hand, by adopting a higher delta voltage for the time being, we may then ultimately, when our load densities become heavier, Y-connect that and have a voltage suitable for the densities of that time.

R. E. Cunningham: I want to ask Mr. Crawford what happens when their primary phase wire falls on the ground. We have had some very serious and expensive accidents; our primary wires have fallen on the ground and lain there some time before we discovered them, and in the meantime caused troubles. To us, taking care of that feature and fully protecting the public is more important than possibly saving a little copper by using a common ground return.

Our state law requires that where the higher voltage lines such as 11-kv. and 15-kv. circuits are paralleling telephone toll lines and become grounded, we must discontinue the service until the ground is cleared. From the hazard to the public it has become a practise with us, even though it does not parallel a toll line, to pull off the circuit until the ground is cleared. On a delta-connected system we have ground detectors which will show us when our circuit is on the ground, but with a Y-connected system such as the 4-kv. we are still hunting for the answer. If Mr. Crawford could, I wish he would give us what his experience has been and what is the accepted practise of taking care of cases where the primary wire falls on the ground.

We have only recently begun the use of automatic reclosing switches having installed two smaller substations with such equipment on the 4-kv. outgoing lines. We arbitrarily adopted the practise of reclosing the first time after 2-sec. interval, the second time, 15 sec. and the third time 30 sec. If the short circuit still remains on the circuit, the switch then locks out. I would like to know what Mr. Crawford's practise is in that regard.

L. R. Gamble: I note that Mr. Crawford has planned his system somewhat in the way the telephone engineers have been planning their systems for the past several years. It always seemed to me that it was a very good scheme. However, very few companies today are doing that thing, planning for the future.

Regarding the matter of diversity in load, on distribution circuits, I note Mr. Crawford has arrived at 1600 watts per residence. In accordance with tests now being made by the National Electric Light Association, on the Electric Range Committee of which I am the engineer in charge of collecting all the data and making the reports, we have arrived at a similar figure on our more or less superficial tests. The 1600 watts per residence is on the basis of about 150 residences, and takes into account the diversity so that in considering a distribution network such as Mr. Crawford has considered here, the figure is probably fairly close. However, in radio systems, that figure is going to be somewhat higher as the diversity factor will be smaller for a smaller number of residences.

I have been more or less a dyed-in-the-wool radial fan. I have not particularly liked the network system. As time goes on, however, it seems that due to improvements in apparatus, and varied schemes in working out different problems in practise, the network system for the higher-density loads is the coming system. No doubt it is in underground systems, but in overhead systems, there seems to me to have been some sort of question.

There is one question I wanted to ask Mr. Crawford. In laying out his system for the future, he figures that he will not have

1. A. I. E. E. JOURNAL, October, 1925, p. 1063.

to rebuild or make any very material changes as the load grows. Considering this, does he use the butt-treated pole? Of course, I realize in asking this that not only does the butt of the pole decay in certain localities, but sometimes the top is also subject to rot.

There is one other point, and that is regarding trees. By the extension of the primaries to a considerable length and interlacing them as Mr. Crawford does, he is subjecting his line to tree interference which is very considerable. All distribution engineers and power men realize the disadvantage of trees, and, so long as we are going to have the "city-beautiful" idea, which luckily a great many cities have not yet adopted, our troubles will be ever increasing.

Digressing a little from Mr. Crawford's paper, there is one subject which should be of interest to distribution engineers and that is the painting of poles. An engineer is an artist to a certain extent; probably in the negative sense. The idea is that he should be able to put these poles in the streets and paint them such a color as to paint them out of the picture instead of into it. Of course, we don't all paint our poles. In some places it is required by ordinance. But I think we ought never to paint a pole a pea-green color.

F. H. Mayer: It has been found in designating electrical grounds for substations and power houses that it is more practical to ground non-current-carrying structures by means of a network, supplemented by one or two ground electrodes, than to ground the various structures by numerous electrodes.

A well designed grounding system must serve two general functions—

1. It must be designed so that its operator can come in contact with any non-current-carrying structure with safety at any time, and

2. It must permit of continuity of service.

The safety feature is accomplished by the metallic network, because a condition is approached similar to that of a station that is constructed on an immense metallic plate, thus tending to keep the potential gradient at the time of an electric failure to practically zero. The control of the potential gradient permits of the grounding of 220-kv. transformer neutrals and cases to the network with absolute safety to the operators.

The continuity of service is brought about by a more reliable relay performance and due to the fact that there is a low-resistance path from any part of the structure there is no tendency for high-voltage current to pass through the control board or other vital parts of the station.

So far as local failures are concerned the network suffices. However, if failures occur foreign to the station, the ground current returns to the station transformer neutrals through the earth and finally is picked up by the electrode that supplements the network, or if an overhead ground wire is used some of the current will return over it.

The overhead ground wire may not be essential where it is possible to extend the ground electrode into a stratum of permanent moisture and it is reasonably sure that the same stratum is again cut at the other stations. This is not always practical in rough areas, and in such cases the overhead ground wire serves a very good purpose, in that it furnishes a lower-resistance path than what is possible through the earth and ground electrode. Most of our power houses are located in mountainous country and such is our experience.

The point that can be gained, I think, is that on distribution systems feeding consumers in a hilly section, for the safety of human life, it is of prime importance, to furnish some reliable metallic return. This can be accomplished by grounding all transformer cases and neutrals to the water pipe or by conductors as outlined by Mr. Crawford.

It has been found that water pipes are not always reliable. Our experience showed in one instance that the pipe supplying the operator's cottage with gas was of lower resistance than the water system. In this particular case, the water system was connected to the transformer cases through the transformer-cooling system. The gas main was connected to the water main through the automatic water heater and at the time of an electrical failure on the 60-kv. switching rack the ground current that flowed through the water heater was sufficient to destroy the heater coil.

It may be possible that this water system also had insulated sections. At any rate, it only goes to show that water-pipe grounds are not always reliable.

M. T. Crawford: I have been very much pleased at the evident appreciation of the policy of looking into the future as far as possible. I believe it is a fundamental responsibility for us, as engineers, to do this, inasmuch as the managements of our respective companies rely on us to a large extent in connection with making heavy investments which are not readily changed.

Mr. Gamble raised a question in regard to the use of networks as a general principle. That seems to me one of the fundamental necessities if we are to build for the future. Five years ago the Puget Sound Power and Light Company installed an a-c. low-voltage network in the Seattle underground district, which was the first one in the country to employ the principle of power-directional relay protection for interconnecting transformers on different feeders on the same system of mains. After these years of operation, we have felt that it is justified, and therefore, the network principle was considered in connection with future plans for the residential areas.

We had in mind building a distribution network something similar in principle to a fishnet, which might be suspended at a certain elevation above the floor. As various articles were thrown on this fishnet, tending to sag it down at certain points, supports in the form of wire or rope from the ceiling could be installed near those points, which would bring it back to level. They correspond to feeders from the substation, running out to tap the network where the load is heavy, bringing the voltage of the network up to the normal value.

Mr. Heinze referred to Dr. Ryan's prediction of one kilowatt per capita and interpreted that to result in approximately 19,000 kw. per sq. mi., and compared it with the 6250 kw. per sq. mi. load density mentioned in this paper as presently to be anticipated load.

I think that it should be borne in mind that the one kilowatt per capita or 19,000 kw. per sq. mi. includes downtown commercial loads, industrial power, and other loads in the city, whereas the figure of 6250 kw. in the paper refers solely to the residential-lighting and domestic load. In the same areas 13,000-volt loop feeders are run for large industrial power customers and as stated in the paper, their loads are not included in this load-density figure. Data are being collected now by the a-c. low-voltage network subcommittee of the National Electric Light Association, and I have in my hands for the report of that committee load-density figures from various sections of the country in the larger cities and the figures of 19,000 kw. per sq. mi. would be very low indeed unless it was an average of both light and heavy load densities, inasmuch as in the central part of cities like Chicago and New York the load densities aggregate 190,000 to 200,000 kw. per sq. mi. The area immediately surrounding this hotel in Seattle now has a load density of over 100,000 kw. per sq. mi.

Mr. Cunningham asked about our experience with one wire on the ground during trouble. We have had both experience with the delta system, ungrounded, and more recently with the grounded neutral in this respect. We find that grounded-neutral system is very much more apt to trip out the feeder at the station, in case of a feeder on the ground. In fact, with the delta system, we have had partial grounds persist three or four days at a time, which we could not locate, which were not apparently causing any dangerous condition, and sometimes cleared themselves up;

but on the grounded-neutral system, if we get a ground at all, it is very apt to build up into a serious one in a short time, causing the feeder to trip out.

Mr. Cunningham also asked about the re-closing features in our automatic substations on these grounded-neutral 4500-volt feeders. At the present time we have the feeder switches set to reclose after 30 sec. when they trip out from overload and after reclosing three times they lock out. Then, of course, we have to find the trouble on the feeder before it can be put back in service. In a considerable proportion of the cases, however, before the third trip-out occurs, the short circuit either burns itself entirely clear, or for some other reason is broken, so the feeder stays in after the first or second reclosure.

Mr. Gamble asked about butt-treatment and painting of poles. We have not gone into butt treatment to any considerable extent as yet, although a good deal of investigation has been under way, and we have had sample carloads of poles treated several ways, not only with butt-treatment, but with full pressure treatment of the pole as a whole. On Puget Sound, however, conditions are probably the least favorable for economy in connection with the butt-treatment or other treatment of poles, inasmuch as the cedar grows locally and is always obtainable at a lower price than in most other parts of the country; furthermore, we have found that where cedar is reset as a pole in the same soil in which its native growth occurred, it lasts very much longer, and we have thousands of poles which are now 20 years old which were not treated at all originally, and which still have sufficient strength, although the average life will probably not exceed 18 years. Where poles will live 18 to 20 years without treatment, it is a grave question as to whether a large increase in initial investment is to be incurred from which no return will be obtained until at least 18 to 20 years later. As other changes occur, such as the building up of the country, perhaps underground requirements may necessitate the removal of a considerable number of the poles within 20 years.

We paint all poles set in the city a very dark green except the 6 ft. next to the ground, which is painted black. With this arrangement, poles set up through shade trees are very unobtrusive. The tree-interference problem with us is a serious one, as with Mr. Gamble and others, but we have an arrangement whereby once each year we organize a tree-trimming crew which works under the supervision of a representative from the city park board, and the city ordinance permits us to trim trees in parking strips; in fact, requires that it be done by the power company. The trimming work done in this way tends to keep the trees at least out of the primaries.

Mr. Mayer pointed out in the discussion an instance of a water-pipe ground which did not prove reliable. But I think that this is something which it is quite important to emphasize here, and it is not so much the reliability of any one water-pipe ground as it is the reliability in the aggregate of a large number of such grounds. The grounding is done on the 4500-volt grounded-neutral system, primarily as a safety precaution, not as a means of returning neutral current, and in any construction or design for the purposes of safety precaution, a multiplicity of small precautions are more reliable than one single large one. There was a case not long ago in Victoria of a fatal injury where the court, after hearing considerable expert testimony, was of the opinion that the injury was primarily the result of water-pipe grounds not having been made. The local light and power company had made as good grounds as they could, but the soil being very rocky these grounds were entirely inadequate. The local authorities would not permit them to make water-pipe grounds on individual services. After collecting considerable data and testimony, it was the opinion of the court that such grounds should have been provided as a precaution for the safety of the public.

SPANS HAVING SUPPORTS AT UNEQUAL ELEVATION[1]

(Smith)

Seattle, Washington, September 15, 1925

F. K. Kirsten: I wish to congratulate Mr. Smith on his courage in using the catenary equations for the analysis of spans supported from points at unequal elevations, and I would also like to make some supplementary comments.

We know that the more closely we wish to describe a physical phenomenon by means of mathematical formulas, the more involved and unwieldy these formulas become. As an illustration, we might use the simple equation of a circle to express the location in space of a suspended cable, and describe actual conditions with sufficient accuracy although the assumptions involve considerable error. By a closer analysis of the forces in action we find, however, that the parabola describes actual conditions better than the circle and hence the application of the parabola yields greater accuracy, although the mathematical operations are more involved. But still a considerable error is made in the assumption that the weight per unit projected length of the span is uniform along the span. The demand for greater accuracy forces us to base our mathematical formulas upon the assumption that the weight per unit length of span, measured along the span, is constant. This assumption leads us to the catenary, a rather involved mathematical stratagem. This mathematical form is rather difficult to handle, especially if temperature changes accompanied by stress changes must be covered by its use. And still the catenary equation does not describe conditions with absolute accuracy. Since the tension changes along the span, the weight per unit length of cable cannot be uniform. But an attempt to involve this actual condition in the modification of the catenary form would lead to unmanageable expressions.

It will be apparent from a perusal of Mr. Smith's work that the chief difficulty in applying the catenary equation to spans of unequal elevations resides in the introduction of the slope of the suspension points into equations which are already complex enough for ready manipulation. Especially do we feel a naturally increasing reluctance to use the catenary analysis if changes of wind and ice loading together with temperature variations over a considerable range must be accounted for by proper mathematical operations with the catenary form. It is, therefore, in my opinion, a step in the right direction to adhere to the simple catenary forms which Mr. Smith ingeniously introduces into his second method instead of using the first method supported by equations **12**, **14** and **15**.

We now have, thanks to Mr. Smith's work, a simple catenary analysis of spans of unequal elevation, and there cannot be any excuse for the use of parabolic forms in the future. It must be remembered, that the catenary method is independent of fixed mass and space units, hence all span conditions which may occur in practise may be expressed by a series of curves from which by interpolation any span, at any slope, for any size or material of cable or any temperature range, may be read at once. This set of curves is as readily applied, without modifications by constants, in continental Europe where the metric system is used as in the lands of inches, pounds and quarts.

Another important finding in Mr. Smith's paper I believe is the discovery that the point of maximum deviation from a straight line connecting any two points of unequal elevation of the cable in suspension occurs midway between the points of support in the middle of the span. This naturally facilitates a check upon the strain of a cable from points of unequal elevation by dropping targets from point B_2 to point A, of predetermined length, the line of vision touching the point of maximum deflection from the line joining these two points.

R. J. C. Wood: Our engineering department has done

1. A. I. E. E. Journal, December, 1925, p. 1352.

a good deal of work in calculating sags and we went into this question of catenary versus parabola quite fully and find that up to about a 1000-ft. span, the parabola is practically a satisfactory curve to use. It must be remembered that after the mathematician has figured out the sag of the line, some fellow in overalls is going to pull that line up as near as he can to the predetermined either sag or tension.

We have been a little undecided as to whether to use the sag or the tension in the line as the criterion. At one time we have used one and at another time the other. We have finally decided to use a dynamometer to measure the tension in the new line. The maximum tension under worst conditions will be about 12,000 lb. and under ordinary stringing conditions may be 6000 or 7000 lb. The dynamometer will probably read within 200 lb. so that any extreme refinement of calculation as to the desired tension is not necessary.

I do not wish to detract in any way from the fine work of mathematicians who calculate these things because, while we may be able to use the laws of a parabola up to a certain point, yet we depend upon the mathematician to tell us where that point is and from where on we should use the more accurate formula. We have ourselves used the catenary formula in all long-span work.

Our spans run up to about 3000 ft. and for that length of span the catenary is necessary. We have had to go a little further than indicated in Mr. Smith's paper, because we have found it quite necessary to calculate clearances to ground under wind conditions. In building the line on a hillside it is not only necessary to know the vertical clearance in still air, but it is quite essential to know that the line will not blow onto the ground when the wind is crosswise, so we have to calculate those conditions of load applied side-ways.

It leads to some very interesting mathematics when there are, for instance, two spans which are dead-ended at the outer ends and hanging on a string of suspension insulators at the middle support, and the wind blows side-ways, because the two spans then no longer remain in a plane but becomes a warped figure and the catenary calculations become quite involved.

C. E. Magnusson: Reference to the parabola by Mr. Wood leads me to bring out a point on the use of hyperbolic functions. Many engineers seem to think that using hyperbolic functions in connection with engineering problems is throwing out a smoke screen to prevent the reader from following the argument. They do not appreciate that for certain types of problems hyperbolic functions become a very convenient means for obtaining accurate solutions. A few years ago while discussing a problem with a nationally prominent engineer, one who has presented many papers before the Institute, I suggested that for an accurate solution hyperbolic functions should be used, and was astounded to find that he had no idea as to what type of problems would require hyperbolic functions. As there may be others in the same predicament let me state that the basis for using circular or hyperbolic functions is simply this: A rotating vector of constant magnitude can be fully represented by circular functions but if the radius vector varies in length while changing in phase position hyperbolic functions fit the case. For example the voltage and current functions along a transmission line vary in magnitude as well as in time-phase position and hence require hyperbolic functions as they cannot be correctly expressed by circular functions.

R. W. Sorensen: I want to second the motion on hyperbolic functions. Dr. Kennelly of Harvard has been trying for years to get us to use them. I have been trying for about fifteen years to get engineering classes to use them, and they use them just as readily as they use trigonometric functions, if you once start them off.

L. J. Corbett: The paper given by Mr. Kirsten[2] a number of years ago is, I think a classic in its field of the application of hyperbolic functions to catenaries and long spans. I think Mr. Smith's paper is a very creditable companion paper to that one.

I like particularly Fig. 4 in which the common point A is used as a basis instead of the usual method, although I have not had time to check it and see whether there are particular advantages to be gained over the old method of calculating sag from the inclined line between A and B.

Mr. Smith, in his discussion, brought up also a point in which we were very much interested in the re-insulation of the Carquinez crossing of the Pacific Gas & Electric Company, and that is the difference in expansion between a long span and a contiguous short span. If you can, visualize that crossing. On the south side the anchors are an average of probably 80 ft. from what is called South Tower. Then comes the long span of 4427 ft., then a span of 1350 ft. and then a final span of 335 ft. to the other set of anchors. On the high tower between the 4427-ft. span and the 1350-ft span, was placed a saddle with a sliding top. This was to allow for a difference in expansion between the two spans and to insure a vertical reaction on the tower. We calculated by a number of methods, but chiefly we went back to the original hyperbolic functions, and we thought that, taking all things into consideration we might expect a possible travel of 5 in. We allowed for a travel of somewhat more than that, 8 in. being the final figure allowed,—4 in. in each direction.

The saddle was placed on roller bearings which were immersed in grease so as to offer the very freest possible travel for the cable. The operating department tells me that in the past year according to the marks on the saddle, there has been a travel of only 1 in. so it is questionable how successful our calculations were. There is still room for improvement in our methods of calculation for long and important spans.

M. T. Crawford: I find Mr. Smith's paper very interesting in that he has gone into unequal supports, something which seems to have been more or less avoided in considerations of span problems. I would ask if he could suggest a method of approach toward the solution of a problem that we have. At one previous Pacific Coast Convention, a paper[2] was presented describing transmission-line construction in crossing Stampede Pass in the Cascade Range, where the loading conditions were very extreme at certains times of the winter, and where it was found advisable on account of the unequal loading which would come alternately on successive spans to change all dead-ends to a suspension form of conductor support, doubling up the insulator springs with yoked attachment at the suspension point.

The changes described in the previous paper have proved eminently successful in eliminating the operating troubles we had of jerking insulator strings in two. In trying to calculate the sags which would result from unequal loading in successive spans, we found a complication came into the matter where an entirely suspension form of construction was used, and where the towers were at different elevations, in that heavier loading in one span would pull the suspension strings out of the vertical position. This would make a change in the length of conductor in the span, location of points of support, and other factors, which are assumed constant in most of the ordinary methods of approaching the subject.

We worked it out fairly closely by making assumptions and trials, but found that the extreme condition which we might assume would occur when the insulator string was pulled out to a position approximately tangent to the catenary. This would result in the wire being down in the snow in winter conditions, but we have never found in practise that it went that far, because there was always some tension in the adjoining spans which would prevent the strings from pulling that far out.

I would like to have Mr. Smith add some discussion or suggestions as to how we might approach the problem of calculating the result of extremely unequal loading in the successive spans where the suspension form of construction is used.

2. Trans. A. I. E. E., 1917, p. 735.

2. Transmission-Line Construction in Crossing Mountain Ranges, by M. T. Crawford, A. I. E. E. Transactions. 1923, page 970.

G. S. Smith: I would like to thank Mr. Wood for mentioning a point I did not have time to bring up in the presentation and perhaps did not make clear in the paper; that is, that the method presented was intended primarily for long spans or special problems. It would usually prove too laborious for a single short span. However, where the Kirsten method is applied to the various symmetrical spans encountered in the usual line, it requires only a small amount of additional work to compute, by the method presented here, the remaining spans whose supports are not at the same elevation, since the cable used is commonly uniform throughout.

In discussions by Dr. Magnusson, Professors Kirsten and Sorensen, a more general use of hyperbolic functions was advocated. My experience has been somewhat similar to the instances mentioned. While most of us are more or less reluctant to use hyperbolic functions freely, I believe it is largely because of two reasons: first, we have never become accustomed to think in terms of such functions; and second, in attempting to use them we find it difficult because so few good tables of hyperbolic functions are available. In some previous work in connection with transmission-line design, I found it necessary to compute sufficient tables for this particular use. These tables will be found in one of the University of Washington Experiment Station bulletins referred to in the paper.

Messrs. Corbett and Crawford pointed out some very interesting problems in this same connection; problems which might be termed those of "variable spans." A similar problem was encountered in the design of "The Narrows" span of the Tacoma Lake Cushman Project mentioned in this paper. It was in an attempt to apply the Kirsten method to such problems that I found it desirable to first work out the problem of spans with supports at unequal elevations. Thus far I have found no direct method of attacking such problems, but the possibility of finding such a method seems entirely feasible.

DISTRIBUTION LINE PRACTISE OF THE SAN JOAQUIN LIGHT AND POWER CORPORATION[1]

(Moore and Minor)

Seattle, Washington, September 17, 1925

R. E. Cunningham: I wish to refer to the described methods of voltage regulation in the commercial district at Fresno using regulated circuits, tied in with circuits feeding directly from the bus. It would seen that this would cause considerable circulating current.

L. J. Moore: Referring to Mr. Cunningham's comments, I am submitting herewith actual readings taken on the feeders in the City of Fresno, which are shown in Fig. 16 of the original paper. Readings *A* and *C* were taken with the two regulated feeders carrying the load, and then the switches were closed on the three alley feeders which are unregulated and readings *B* and *D* were taken. Ammeters were installed in current-transformer secondaries on two phases of each circuit and readings taken. Where no ammeter readings are shown for the alley feeders, the switches at the substation were open.

It is noted from the readings that circulating current is set up when the substation bus voltage fluctuates to an extreme degree, and as indicated in the original paper, no attempt is made to keep the switches in when the substation voltage is extremely low. As a matter of fact, the San Joaquin system is not fully regulated and to some extent the system voltage is varied by increased feeders on generators so as to raise the entire system at time of peak loads. This naturally tends to keep up the bus voltage in Fresno at the time of system peak and reduces the amount of regulation required, and this, of course, naturally limits the circulating current. For that reason it has been possible to operate all of these lines tied together to good advantage on numerous occasions.

Kw. Total	Volts Bus	Current in Feeders: Kern		Tuolumne		Fulton Van Ness		Broadway Fulton		H Broadway		Total	
(*A*) 2800	121	280	260	220	240	—	—	—	—	—	—	570	500
(*B*) 2800	122	50	60	40	60	160	160	170	160	120	120	540	560
(*C*) 3300	116	310	350	340	360	—	—	—	—	—	—	700	710
(*D*) 3200	116	290	330	330	300	60	110	100	148	80	128	860	1016

1. A. I. E. E. Journal, November, 1925, p. 1201.

ILLUMINATION ITEMS

By the Lighting and Illumination Committee

DEPRECIATION OF THE REFLECTING PROPERTIES OF WHITE PAINTS

The illuminating engineer of today has made much progress in a study of the various factors which are involved in the installation and maintenance of an efficient and effective lighting system. He knows full well the influence that the type of luminaire, its spacing and mounting height and the color of the surroundings have on the character of the illumination produced. He is also quick to realize the uselessness and ineffectiveness of even the best of lighting systems if they are allowed to depreciate because of an accumulation of dust and dirt. He knows, too, that the majority of lighting systems are largely dependent for their effectiveness upon the general lightness in color of the surroundings. The illuminating engineer is not alone in his interest in these factors, however, for the architect, the plant executive and the building manager should be concerned equally as much, if not actually more, in the adequacy of the lighting system.

In view of the fact that light colored ceilings and side walls play an important part in the effectiveness of lighting, and also that pure white paint is generally conceded to be the most desirable for these surfaces—at least from an illumination standpoint—a series of tests* have recently been conducted on the reflecting properties of various kinds of white oil paints. The object of these tests was to determine the kind of white paint having the highest initial reflecting power when applied to various surfaces and also to determine the rate of depreciation of the various paints under different conditions. Twenty-six samples of paints were selected and applied to the test surfaces in accordance with the recommendations of the various paint manufacturers.

*"The Reflecting Properties of White Interior Paints of Varying Compositions," a paper presented by A. L. Powell and R. B. Kellogg, before the New York Section of the Illuminating Engineering Society on Nov. 12, 1925.

Three different kinds of surfaces were used in order to determine whether or not the type of surface had any effect on the reflecting properties and rate of depreciation of the paint. These test surfaces of wood (white pine), finishing concrete, and galvanized sheet iron were made into the convenient test size of 5 by 7 inches. The concrete samples were aged for eight weeks before they were used in order to lessen the possibility of destructive chemical action.

Two sets of specimens were prepared with each of the 26 paints on each of the three different surfaces. One of these sets were sealed up in a dust proof cabinet with a glass front, and exposed to direct north skylight so as to determine the depreciation of the paint due to light alone.

The other set of specimens was suspended close to the ceiling in a factory interior in which a certain amount of very small metallic and graphic particles were suspended in the atmosphere. In addition to these, the atmosphere contained a fairly high percentage of the products of combustion as produced by the many gas burners used in the drawing of tungsten wire. The test on these specimens would show the acquired depreciation which a paint would have under conditions which might be considered slightly more severe than normal industrial service.

The entire test covered a period of about 20 months and photometric readings were taken of each sample at intervals of 16, 31, 49, 71 and 88 weeks. It can be readily seen that this involved a considerable amount of photometric work and for this reason a rather inexpensive modified sphere or icosahedron was constructed for the purpose. In addition to this modified sphere, a small photometer and projection lantern were required.

In the actual determination of the reflection factor of a sample which has been placed in the sphere, the sight tube of the photometer is first directed upon the walls of the sphere and a reading of apparent foot-candles is made. This is considered to be the illumination incident upon the sample. The photometer is then directed toward the sample and a second reading is taken. This is considered the light reflected from the sample. The ratio of those two readings is, of course, the reflection factor of the sample. In order to maintain the accuracy of the results obtained a freshly scraped block of commercial magnesium carbonate was used as a standard at regular intervals.

The results of the test as a whole, disclosed some interesting facts. It was found that the initial reflection factor of the 26 types of white paint tested showed an average value of 81.1 per cent. The maximum value found was 87.6 per cent for a flat paint with titanox lead and free zinc as pigment material. While the minimum reflection factor was 75.5 per cent for a flat paint with lithophone as a pigment material.

The average results as obtained from all the specimens in the two sets of tests reveal the fact that with the specimens in the glass covered cabinet, the character of the material to which the paint is applied has practically no effect on the rate of depreciation, while with the set of specimens exposed to factory conditions the metal and concrete samples drop off somewhat more rapidly than the wood specimens. The curve of Fig. 1 shows this clearly.

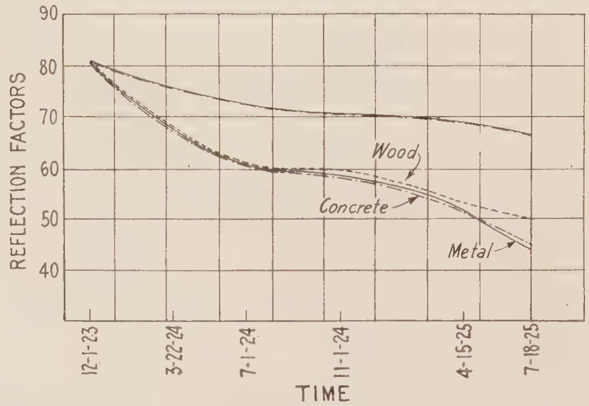

FIG. 1—AVERAGE DEPRECIATION CURVES OF ALL SPECIMENS BASED ON THE MATERIAL TO WHICH THE PAINT IS APPLIED

Upper curve—Cabinet set
Lower curve—Factory set

The curve in Fig. 2 was obtained by grouping all specimens having the same type of finish (gloss, eggshell or flat) regardless of composition, and averaging the test values. Initially the flat white group shows the highest reflection factor and, contrary to common opinion, the average rate of depreciation is about the same for all types of finishes. This may be explained by the particular character of the dirt which accumulated in the factory test. It was of a slightly greasy

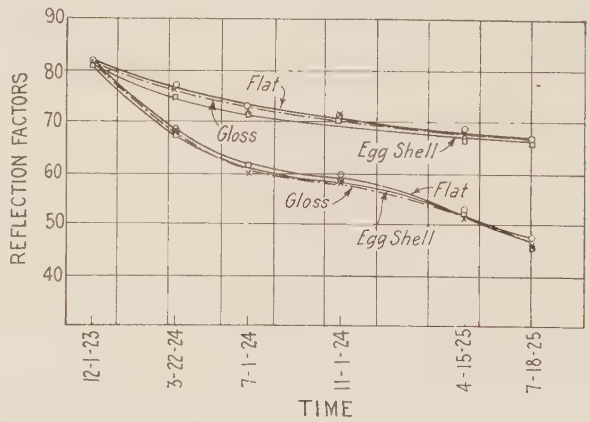

FIG. 2—AVERAGE DEPRECIATION CURVES OF ALL SPECIMENS BASED ON TYPE OF PAINT FINISH

Upper curve—Cabinet set
Lower curve—Factory set

carbon nature which would cling with equal tenacity to flat or glossy surfaces.

By grouping specimens of the same pigment together and averaging values regardless of the character of finish, the results obtained seemed to indicate that the paint having titanox as a part of the pigment had the

TABLE I
THE REFLECTING PROPERTIES OF WHITE PAINTS

Specimen No.	Basic Pigment	Type of finish	Initial reflection factor	Average reflection factor during 20 months Cabinet Specimens	Factory Specimens	Appearance at end of test
1	Lth and Zn O	Undercoat Semi-Gloss	81.9	73.1	64.7	Grayish
2	Zn O and Lth	Eggshell	82.5	71.3	62.0	White
3	Titanox Pb and Zn	Flat White	86.9	76.3	65.7	White
4	Lth Pb and Zn	Gloss	86.6	75.3	63.5	Bluish
5	Lth Titanox Pb and Zn	Eggshell	84.3	75.3	63.2	White
6	Zn O and Lth	Flat White	85.2	76.4	64.3	White
7	Zn O and Lth	Gloss	83.7	74.8	57.6	Bluish
10	Lth	Enamel	80.4	73.75	57.9	White
11	Lth	Flat White	82.7	75.9	61.8	Cream
12	Lth and Zn O	Gloss	81.1	74.5	59.15	White
13	Lth	Eggshell	81.7	74.4	61.8	Cream
15	Lth	Flat White	81.7	74.8	60.9	White
16	Lth and Zn O	Gloss	82.2	74.8	61.1	White
17	Lth	Semi-Gloss	78.5	72.8	60.6	Cream
18	Zn O	Semi-Gloss	75.8	68.8	57.2	White
20	Lth	Flat-White	76.3	68.0	59.2	White
21	Lth	Eggshell	79.75	69.4	58.3	White
22	Lth	Gloss	77.4	68.7	52.9	Cream
24	White Pb	Flat White	77.25	68.5	59.8	White
27	Zn O	Enamel	83.5	65.8	59.65	White
29	Pb and Zn O	Eggshell	75.1	68.3	55.5	Cream
30	Lth and Mgsi Silicate	Eggshell	80.0	70.7	60.7	White
32	Lth and Zn O	Gloss	80.1	73.8	61.5	White
33	Lth and Mgsi Silicate	Flat White	80.0	72.5	62.2	White
34	Lth	Eggshell	81.4	73.5	61.7	White
35	Lth	Gloss	82.1	73.6	63.2	Grayish

highest initial reflection factor, with those of lithophone, lead, and zinc following in the order named. The rate of depreciation of the different groups is in this order also. These results, however, do not tell the whole story, for there may not be enough varieties of certain types to give good average figures, whereas with other types there may be instances of high values grouped with exceptional low values.

The question naturally arises as to whether a distinct chemical action took place with those specimens exposed to factory conditions. At the conclusion of the test all samples which had been hanging in the workroom were removed and carefully cleaned with a fine grade of soap and hot water. This was more carefully done than would have been the case if an ordinary workman was called upon to clean a paint surface. Readings were then taken of each specimen and it was found, in general, regardless of finish or composition, that the reflection factor of the cleaned specimen was very close to that corresponding specimen which had been kept in the glass cabinet.

The grand general average showed the factory specimens after cleaning to be about 2 per cent below those of the control set. The maximum departure was 5.7 per cent less, and on the other extreme, one specimen showed 1.8 per cent higher reflecting power. These deviations are so relatively small as to be well within the limits of error of such measurements.

The question naturally arises as to what is the best type of paint for different conditions, and one must stop to analyze what is required of the paint. The initial reflection factor certainly does not tell the whole story. One paint may have a very high initial value and its rate of depreciation may be quite rapid; another may have a lower initial reflection factor and yet over a period of time actually reflect more light—in other words, it depreciates at a lower rate.

DIELECTRIC CONSTANT, POWER FACTOR AND RESISTIVITY OF RUBBER AND GUTTA-PERCHA

Technologic Paper, No. 299, of the Bureau of Standards, by H. L. Curtis and A. T. McPherson, comprises a careful study of the dilectric constant, power factor, and resistivity of rubber and its compounds, and of gutta-percha. Crude rubber has a lower dielectric constant than either gutta-percha or vulcanized rubber, the value of the latter depending on the conditions of vulcanization. Vulcanization by sulphur alone produces a higher dielectric constant than vulcanization with the aid of an accelerator. The addition of a filler generally increases the dielectric constant, sometimes by as much as 200 or even 300 per cent. Dried samples of both rubber and gutta-percha have a lower dielectric constant than those which contain absorbed water. Vulcanized rubber may have a lower dielectric constant than gutta-percha.

The power factor of crude rubber is about the same as that of gutta, the hydrocarbon of gutta-percha. Crude rubber, vulcanized rubber, and gutta-percha all have about the same resistivity. The incorporation of some substances in vulcanized rubber increases the resistivity.

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Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

The Institute is not responsible for the statements and opinions given in the papers and discussions published herein. These are the views of individuals to whom they are credited and are not binding on the membership as a whole.

Midwinter Convention February 8-11

All is ready for the opening of the Midwinter Convention in New York, February 8-11, with headquarters at the Engineering Societies Building. The advance indications show that there will be a large attendance. An unusually large number of requests for advance copies of the technical papers proves that the topics to be presented are of wide interest. The social events also will be of such quality that they will be thoroughly enjoyed.

Among the technical subjects to be presented are transmission power limits, protection, control systems, electrical machinery, measurements, insulation and dielectric absorption, electromagnetism, electrophysics, communication and sound reproduction, and furnace-resistor design. In the list below the titles of all papers are given.

An informal smoker at which entertainment will be furnished by some high-grade talent will be held at the Hotel Astor on the evening of Tuesday, February 9th. A delightful evening is assured on the evening of Wednesday in the dinner-dance which will be held at the Hotel Astor. Paul Whiteman's Picadilly Players will furnish the music. A prominent speaker will be heard in an address of general interest on Thursday evening in the Engineering Societies Building.

Inspection trips will be made to a number of interesting places including the following: The new Holland Tunnel (the vehicular tunnel under the Hudson River), Broadcasting Station W.E.A.F. of the American Telephone and Telegraph Company, The Edison Lighting Institute of the Edison Lamp Works, the Loening Airplane Factory, Kearny Power Station of the Public Service Electric Power Company, Hudson Avenue Station of the Brooklyn Edison Company, Hell Gate and Sherman Creek Stations of the United Electric Light and Power Company, the Bell Telephone Laboratories and a machine-switching central telephone office. The regularly scheduled trips will be made on Wednesday afternoon though small parties may visit some of the places at other times.

Two intensely interesting lectures, on topics which engineers do not often have the chance to hear presented by foremost authorities, will be delivered on Thursday evening, in the Engineering Auditorium beginning at 8:15 P. M.

Dr. Alexis Carrel will talk on some developments of modern biological research. A motion-picture demonstration will illustrate the points of the address. Dr. Carrel is a member of the Rockefeller Institute for Medical Research and a winner of the Nobel Prize. He is widely known for his accomplishments in the field of medical and biological research and, in addition, is a magnetic speaker.

Dr. Carrel will deal particularly with the life of tissues outside of the organism. The motion pictures will show the actual growth of living cells outside of the living organisms from which they were taken. Some strains of cells in Dr. Carrel's laboratory have been living and growing under artificial conditions since 1912.

Major Allen Carpe, of the American Alpine Club, will describe "The Ascent of Mount Logan." This mountain is 19,850 ft. high, and was the highest unclimbed mountain in North America when the ascent was made last summer. This also will be illustrated with motion pictures.

Mount Logan, in Yukon territory, is probably the largest mountain mass in the world, in the center of the largest glacial area outside of the polar region. On this expedition, Major Carpe obtained some most remarkable motion pictures covering the work of approach and ascent of this mountain, including packing and hand-sledding over the lower glaciers, establishment of the higher camps and pictures taken on the actual summit of the mountain.

All local arrangements have been made by the Convention Committee and subcommittees. The general committee is as follows: H. A. Kidder, Chairman, H. H. Barnes, Jr., G. L. Knight, E. B. Meyer and L. F. Morehouse. Chairmen in charge of features are as follows: Entertainment, H. H. Barnes; Smoker, G. W. Alder; Inspection Trips, H. Y. Hall; Dinner-Dance, J. B. Bassett, Special Meeting, H. S. Sheppard and Finance, G. L, Knight.

PROGRAM OF THE MIDWINTER CONVENTION

MONDAY MORNING

Registration
Committee Meetings

MONDAY AFTERNOON

TRANSMISSION SESSION

1. *An Investigation of Transmission-System Power Limits*, C. A. Nickle, and F. L. Lawton.
2. *Calculation of Steady-State Stability in Transmission Lines*, Edith Clarke.
3. *Practical Aspects of System Stability*, Roy Wilkins.
4. *Further Studies of Transmission Stability*, R. D. Evans and C. F. Wagner.
5. *Transmission Systems with Over-Compounded Voltages*, H. B. Dwight.

MONDAY EVENING

DIELECTRICS AND INSULATION

6. *Dielectric Absorption and Theories of Dielectric Behavior*, J. B. Whitehead.
7. *Theory of Absorption in Solid Dielectrics*, V. Karapetoff.
8. *Ionization Studies in Paper-Insulated Cables*, C. L. Dawes and P. L. Hoover.

TUESDAY MORNING

PROTECTION, CONTROL AND BUS CONSTRUCTION

9. *Operating Performance of a Petersen Earth Coil-II*, J. M. Oliver and W. W. Eberhardt.
10. *Theory of the Auto-Valve Lightning Arrester*, Joseph Slepian.
11. *Current-Limiting Reactors with Fire-Proof Insulation on the Conductor*, F. H. Kierstead.
12. *Temperature Rise and Losses in Structural-Steel Members Exposed to the Fields from A-C. Conductors*, O. R. Schurig and H. P. Keuhni.
13. *Carrying Capacity of Sixty-Cycle Busses for Heavy Currents*, Titus G. LeClair.
14. *Supervisory Systems for Electric Power Apparatus*, Chester Lichtenberg.

TUESDAY AFTERNOON

TWO PARALLEL SESSIONS, A AND B

(A) ELECTRICAL MACHINERY

15. *Experimental Determination of Losses in Alternators*, Edouard Roth.
16. *No-Load Copper Eddy-Current Losses*, Thomas Spooner.
17. *Mechanical Force Between Electric Circuits*, R. E. Doherty and R. H. Park.
18. *Concluding Study of Ventilation of Turbo-Alternators*, C. J. Fechheimer and G. W. Penney.

(B) COMMUNICATION AND SOUND REPRODUCTION

19. *The Development and Application of Loading for Telephone Circuits*, Thomas Shaw and William Fondiller.
20. *Cipher Printing-Telegraph Systems*, G. S. Vernam.
21. *Refraction of Short Radio Waves in the Upper Atmosphere*, W. G. Baker and C. W. Rice.
22. *High-Quality Recording and Reproducing of Music and Speech*, J. P. Maxfield and H. C. Harrison.

TUESDAY EVENING

Smoker

WEDNESDAY MORNING

ELECTRICAL MACHINERY

23. *Parameters of Heating Curves of Electrical Machinery*, V. Karapetoff.
24. *Rating of Electrical Machinery as Affected by Altitude*, C. J. Fechheimer.
25. *Motor Band Losses*, Thomas Spooner.
26. *Starting Characteristics of Polyphase Squirrel-Cage Induction Motors and Their Control*, H. M. Norman.

WEDNESDAY AFTERNOON

Inspection Trips

WEDNESDAY EVENING

Dinner-Dance, (Hotel Astor)

THURSDAY MORNING

ELECTROMAGNETISM AND PHYSICS

27. *Calculation of Magnetic Attraction*, Th. Lehmann.
28. *The Magnetic Hysteresis Curve*, Hans Lippelt.
29. *Properties of the Single Conductor*, Carl Hering.
30. *Heaviside's Proof of His Expansion Theorem*, M. S. Vallarata.

THURSDAY AFTERNOON

MEASUREMENTS, MACHINERY AND INDUSTRIAL

31. *A New Wave-Shape Factor and Meter*, L. A. Doggett, J. W. Heim and M. W. White.
32. *Practical Application of Vibration Instruments to Rotating Electrical Machines*, J. Ormondroyd.
33. *A High-Frequency Voltage Test for Insulation of Rotating Electrical Machinery*, J. L. Rylander.
34. *The Cross-Field Theory of Alternating-Current Machines*, H. R. West.
35. *Rating of Heating Elements for Electric Furnaces*, A. D. Keene and G. E. Luke.

THURSDAY EVENING

Some Modern Developments of Biological Research, by Dr. Alexis Carrel, Member Rockefeller Institute for Medical Research.

The Ascent of Mount Logan, by Major Allen Carpe, of the American Alpine Club.

Regional Meeting at Cleveland

MARCH 18-19

Plans are practically completed for the Regional Meeting which will be held in Cleveland on March 18-19 with headquarters at the Hotel Cleveland. This will be a two-day meeting and papers will be devoted to the subjects of sectionalized electric drive and electric refrigeration. There will be addresses by prominent men, a dinner, a meeting of Branch Counsellors of the Second District and inspection trips.

SECTIONALIZED ELECTRIC DRIVE

In recent years no more interesting problem has been presented to the electrical engineer than the interlocking of individual motor drives into a controlled group drive. The problem has been so successfully solved that it is possible to control the speed of the group over a wide range and still maintain no variation between the relative speeds of the individual motors of the group. Furthermore, at the will of the operator the fixed relation may be adjusted over a considerable range.

This subject will be presented and discussed before the Institute for the first time at the Cleveland Meeting in the sessions on Thursday, March 18. The various systems will be described by S. A. Staege of the Westinghouse Electric and Mfg. Company, R. N. Norris of the Harland Engineering Company and H. W. Rogers of the General Electric Company.

Plans are being successfully carried out to have present a large number of paper-mill engineers and executives to enter into the discussion of these papers. It was in the paper-mill field that the demand for such a synchronized group drive originated. There it has been so successfully applied that paper has been manufactured at speeds higher than 1000 ft. per min.

It is probable that in many other lines of industry there exist fields for such a drive. Wherever it is necessary to provide for a variation in the speed of the group as a whole and still maintain synchronism between the individual motors of the group a possible field of application exists provided the investment is justified by the advantage secured.

FRIDAY SESSIONS

Two unusual speakers of national reputation have been secured for the second day of the meeting. C. F. Kettering, President of The General Motors Research Corporation, will speak on "Electrical Refrigeration," a subject in which every householder as well as every engineer in interested.

Past-President Farley Osgood, will deliver an address under the heading "Engineering and Humanity."

A dinner will be held at the Hotel Cleveland on Thursday evening, at which a message of welcome will be given by Manager Hopkins of the City of Cleveland and an address will be made by a well-known speaker.

A special inspection trip will be made on Friday evening to the National Lamp Works of the General Electric Company at Nela Park. A number of other interesting trips also may be taken by those at the meeting.

Thorough arrangement of plans and details is in the hands of an able general committee and subcommittees. The general committee consists of: Chairman, A. M. MacCutcheon; Secretary, C. S. Ripley; A. G. Pierce, Vice-President of Second District; C. L. Dows, Ralph Higgins, A. F. E. Horn and Nathan Shute. The chairmen in charge of the subcommittees are: L. D. Bale, Transportation; H. B. Dates, Program; C. L. Dows, Reception; H. L. Grant, Publicity; G. A. Kositzky, Finance; A. M. Lloyd, Registration; E. H. Martindale, Attendance; C. W. Rakestraw, Dinner, and I. M. Van Horn, Trips.

Niagara Falls and Madison, Wis., Regional Meetings in May

Two regional meetings are planned for the coming May, a meeting at Madison, Wis., being scheduled for May 6 and 7 and one at Niagara Falls, N. Y., for May 26-28.

The meeting at Madison will be held under the auspices of Geographical District No. 5. A two-day program is planned and the papers will cover the subjects of rural electrification, power transmission and distribution, cooperati e research relations between colleges and industries, and radio.

The committee in charge of the Madison meeting is as follows: Edward Bennett, Vice-President of District No. 5, J. B. Baily, A. J. Deward, H. R. Huntley, L. E. A. Kelso, Carl Lee and R. G. Walter.

The Niagara Falls meeting which will be held by District No. 1 will be a three-day affair. The technical papers will cover methods of dielectric power-factor measurement, transmission, power plants and other subjects. Arrangements are being made for a special illumination of the Falls, a trip down the Gorge, visits to generating and manufacturing plants and entertainment features.

The general committee in charge of the Niagara meeting consists of H. B. Smith, Vice-President of District No. 1; A. C. Stevens, Secretary; J. R. Craighead, E. D. Dickinson, J. A. Johnson, A. E. Soderholm and A. W. Underhill. J. A. Johnson is chairman of the local committee on arrangements.

Student Convention at Cambridge

Plans are under way for a Northeastern District A. I. E. E. Student Convention to be held in Cambridge, Mass., in the Spring. Arrangements are being made by a student committee headed by the Chairman of the Massachusetts Institute of Technology Branch acting with the advice and assistance of the Executive Committee of the Boston Section.

Tentatively, it is proposed to hold a morning session at which two or three student papers will be presented and a banquet in the eveniug to be held jointly with the Boston Section. The afternoon will be devoted to a number of inspection trips to points in and about Boston. Included in these trips will be the well-known Edgar Station of the Edison Electric Illuminating Company of Boston and the laboratories of the electrical Engineering Department of Massachusetts Institute of Technology.

Future Section Meetings

Baltimore

Mercury-Arc Rectifiers as Applied to Power Development, by H. D. Brown, General Electric Co., Johns Hopkins University. February 19, 8:15 P. M.

Mechanical Power and Trend of Civilization, by C. E. Skinner, Westinghouse Electric & Mfg. Co., Engineers' Club. March 19, 8:15 P. M.

Boston

High-Tension Cable Testing, by F. M. Farmer, Electrical Testing Laboratories. Meeting to be held in the new 750,000-volt testing laboratory of the Simplex Wire & Cable Co., Boston, Mass. February 19.

Connecticut

The Value of Patents. Stamford. February 16.

Power Production. Hartford. March 9.

Lehigh Valley

Automatic Control of Centrifugal Pumps, by Otto Haentjens, Barrett Haentjens & Co., and

Wallenpaupack Hydro-Electric Development, by N. G. Reinecker, Pennsylvania Power & Light Co., Wilkes-Barre. March 26.

Pittsfield

Lightning. Round-Table Discussion, Leader, F. W. Peek, Jr., General Electric Co. February 23.

Earthquakes and Volcanoes, by B. R. Baumgardt, Scientist and Explorer. Illustrated. February 16.

Artificial Refrigeration, by A. R. Stevenson, Jr., General Electric Co. Illustrated. March 2.

Round-Table Discussion. March 9.

St. Louis

Development of Electric Power Generation and Distribution, by Col. Peter Junkersfeld, President, McClellan & Junkersfeld. March 17.

American Engineering Council

ANNUAL MEETING, WASHINGTON, D. C., JANUARY 13-15, 1926

The Annual Meeting of the Amerian Engineering Council was held in Washington, D. C., at the Mayflower Hotel, January 13-15, 1926. About one-hundred delegates and interested visitors were in attendance. The official delegates came from all parts of the country and represented the various national, state and regional engineering societies composing the membership of the Council. In the absence of President James Hartness, of Vermont, who is recovering from a long illness, the meeting was presided over by Vice-President Gardner S. Williams.

The sessions of the Assembly were marked by keen interest, abiding confidence, and constructive action. Those in attendance were gratified with the work accomplished and were inspired with the great sphere of usefulness immediately at hand.

The meetings of the Executive Committee and the Administrative Board of the Council were held on Wednesday, January 13th, at which various matters were considered and recommendations formulated for the consideration of the Assembly of the Council on the following day. These matters are included in the following summary of the principal topics discussed and actions taken by the Assembly on January 14th and 15th.

Department of Public Works and Domain

A conference on Public Works was attended by official representatives from sixty-three engineering and allied technical associations. The Conference approved the draft of a bill providing that the Department of Interior be named the Department of Public Works and Domain. The drafted bill calls for the following four assistant secretaries: an Assistant Secretary having administrative jurisdiction over the Design and Supervision of Architectural Works; an Assistant Secretary having administrative jurisdiction over the Design and Supervision of Engineering Works; and Assistant Secretary having administrative jurisdiction over the administration and execution of the Construction Work of the Department of Public Works and Domain; and an Assistant Secretary having administrative jurisdiction over the Public Domain. Under the provisions of the bill all subdivisions of the Federal Government of an architectural, engineering and construction character would be transferred to the Department of Public Works and Domain.

The Bill will be introduced in the Senate by Senator Jones, of Washington, and in the House of Representatives by Congressman Wyant, of Pennsylvania.

Government in Industry

The Council had been invited to become an affiliated member of the Conference on Government in Industry. This it declined to do. However, it voted to lend its moral support to the purposes of the Conference. This it did by declaring it to be the sense of American Engineering Council that the Government should not trespass upon the field of industry unless it was satisfactorily shown that the Government could better engage in a particular business than private enterprises.

Federal Water Power Commission

In view of the fact that bills have been introduced into Congress proposing to remove the Tennessee and Colorado Rivers from the jurisdiction of the Federal Power Commission, and since other legislation is pending which, if passed, will undermine the Commission, the Assembly approved a resolution of disapproval of all such legislation. The Assembly instructed its Water Power Committee and officers to use all possible means to defeat any legislation that tends to impair the usefulness of the Commission or to destroy the functions thereof as provided for in the enabling act.

Salaries of Federal Judges

The Assembly unanimously endorsed House Bill 3831, "A bill to increase the salaries of Federal Judges," and instructed its Patents Committee to exert its efforts to secure the passage thereof.

Patents

The Assembly passed a resolution authorizing its officers to endeavor aggressively to secure a new building for the Patent Office. They were instructed to enlist the active support of all interested groups. The urgent need for a new building and modern equipment was clearly set forth by the Executive Secretary, who has been serving on a Committee on Patent Office Procedure, appointed by the Secretary of Interior and continued by the Secretary of Commerce.

Street and Highway Safety

Mr. W. B. Powell, Chairman of the Committee on Street and Highway Safety, submitted a most suggestive report. The committee recommended that American Engineering Council alone or in cooperation with other organizations have a study made of:

A. Traffic control signals.

B. Directional and general traffic signs for city streets.

C. Analysis of the physical factors entering into the efficient operation of street intersections.

D. Analysis of the most efficient methods of turns at intersections.

The Assembly approved the report and referred it to the Administrative Board for consideration of ways and means to having the study made.

Reclamation

Chairman H. B. Walker, speaking for the Committee on Reclamation, said the future policy of Federal reclamation should embody the principle that previous to inaugurating any project, there shall be ascertained:

A. The producing capacity of the land.

B. The ability of the land and the project to meet the cost of construction, operation and maintenance.

C. The practical occupation of the land by responsible settlers.

The Committee recommended that American Engineering Council have made under its direction a thorough and an important study of:

A. The fundamental principles involved in a reasonably fixed policy of Federal Reclamation.

B. An administrative plan looking toward the creation of a Federal corporation, controlled by a small board of directors, authorized to administer and enforce congressional acts relating to reclamation.

C. Development of a land settlement plan which may be practical under such corporate administration.

The Assembly adopted the report of the committee and referred it to the Administrative Board with power to have such a study made if means for financing it can be obtained.

Program of Research

Dr. H. E. Howe, Chairman of the Committee on a Five-Year-Program of Research, presented a progress report which was enthusiastically adopted. This program proposes the following studies:

Waste in Agriculture, with special reference to the engineering phases thereof.

Survey of Waste in Industries using Agricultural Products as Raw Materials.

Waste of Power, in the realm of generation, transmission and use of power obtained from coal, oil and gas.

Reclamation of Material Wastes, such as metals, forest products, city refuse and garbage.

The Engineering Approach to the Problem of Labor Supply.

Training and Employment of the Partially Incapacitated.

Industrial Fatigue.

Integration of Industry.

This program contemplates the expenditure of approximately $350,000 during the next five years.

On the basis of past experience and a known source of interest, it is believed the necessary funds can be secured.

Civil Aviation

Announcement was made that the report on Civil Aviation had been completed and issued in book form. This report, made jointly by the Department of Commerce and American Engineering Council, has been most favorably received and will undoubtedly serve a useful purpose during this session of Congress.

Survey for 1926

The Council has secured $25,000 with which to defray the expense of its survey for 1926. This survey will have to do with safety in industry. The details are being developed and a further announcement concerning it will be made in the near future.

Meeting of Washington Sections.

On the evening of January 13th, the delegates in attendance were the guests of the Washington Sections of the A. S. M. E. and the A. I. E. E., at a dinner at the Cosmos Club. Messrs. A. F. Horn, Chairman of the A. I. E. E. Section, and Arthur Adelman, Chairman of the A. S. M. E. Section, acted as "alternating" toastmasters. The following officers and Past Presidents of the A. S. M. E. and A. I. E. E. were called upon and made brief addresses:

William L. Abbott, A. W. Berresford, M. E. Cooley, Ira M. Hollis, F. L. Hutchinson, Dexter S. Kimball, F. R. Low, Farley Osgood, Calvin W. Rice, E. W. Rice, Jr., and Charles F. Scott.

The principal speaker of the evening was Dr. Harold G. Moulton, Director of the Institute of Economics, Washington, D. C., who gave an exceedingly interesting and instructive talk on "The French Debt Problem."

Banquet

The Council sessions concluded with a Banquet at the Chevy Chase Club, Friday evening, January 15th. Mr. Gardner S. Williams, Acting President, presided at the Banquet. A short address was given by President-elect Dexter S. Kimball. The principal speakers were Honorable Hubert Work, Secretary of the Interior, and Honorable D. R. Crissinger, Governor of the Federal Reserve Board. Many prominent members of Congress and government officials attended.

Officers Elected

The officers elected at this Annual Meeting are:

President, Dexter S. Kimball, Dean of Engineering, Cornell University, Ithaca, New York.

Vice Presidents, Gardner S. Williams, Ann Arbor, Michigan, (re-elected) and I. E. Moultrop, Boston, Massachusetts.

Treasurer, Dr. H. E. Howe, Washington, D. C. (re-elected)

Executive Secretary, L. W. Wallace, Washington, D. C., (re-elected by the Administrative Board)

Hold-Over Officers are:

Vice Presidents, O. H. Koch, Dallas, Texas; and A. W. Berresford, New York, N. Y.

The representatives of the A. I. E. E. present were:

A. W. Berresford, John H. Finney, M. M. Fowler, H. M. Hobart, F. L. Hutchinson, William McClellan, Farley Osgood, E. W. Rice, Jr., C. F. Scott, and C. E. Skinner.

Announcement was made of the names of the representatives who will constitute the Administrative Board for the year 1926, consisting of the President, the four Vice Presidents, the Treasurer and representatives of the national societies and the regional districts; the delegation to represent the A. I. E. E., in addition to Vice-President Berresford is composed of:

John H. Finney, Washington, D. C.; D. C. Jackson, Boston, Massachusetts; Farley Osgood, Newark, New Jersey; E. W. Rice, Jr., Schenectady, New York; Charles F. Scott, New Haven, Connecticut, and C. E. Skinner, Pittsburgh, Pennsylvania.

Four alternates were also designated namely:

M. M. Fowler, Chicago, Illinois; William McClellan, New York, N. Y.; A. G. Pierce, Cleveland, Ohio; and E. C. Stone, Pittsburgh, Pennsylvania.

John Fritz Medal Awarded to Edward Dean Adams

The John Fritz medal, established in 1902 in honor of John Fritz, one of the great pioneers in the iron and steel industry to be awarded annually for notable scientific and industrial achievement—the highest honor bestowed by the engineering profession of this country—was on January 15, awarded by the John Fritz Medal Board to Edward Dean Adams, for achievement as "an Engineer, Financier, Scientist, whose vision, courage and industry made possible the birth at Niagara Falls of hydroelectric power." The presentation will be made at a later date.

Born in Boston Mr. Adams has resided in New York since 1878. He was graduated as a bachelor of science from Norwich University in 1864 continuing the pursuit of his engineering studies at Massachusetts Institute of Technology. Mr. Adams has been a fellow of American Society of Civil Engineers since 1891, an associate of American Institute of Electrical Engineers since 1910, Vice-Chairman of Engineering Foundation since its inception, and, for years, an active member and officer of Engineering Societies Library.

It was by his decision that alternating current was chosen for the epoch-making plant of The Niagara Falls Power Company in 1891 as well as the transmission of the power by wire to Buffalo. He personally made extensive studies of the latest forms of electric generators and water turbines in Europe and America. In spite of contrary opinions he adhered to his momentous decision with regard to the kind of electric current and equipment to be used emphatically expressed by Edison and Sir William Thomson (later Lord Kelvin)and now alternating current and direct-connected hydroelectric units are almost universally employed for power development and transmission.

Mr. Adams has been a patron of many expeditions for observing total eclipses of the sun and of other scientific investigations personally participating in some of them. He is a member of the National Research Council, the American Museum of Natural History, for many years a trustee of the Metropolitan Museum of Art, and a patron of the fine arts in this and other countries.

On April 9 last year, a host of friends, men of national and international reputation in many fields of human endeavor, entertained Mr. Adams at a dinner at the Waldorf-Astoria Hotel in celebration of his seventy-ninth birthday.

Most of his long and intensely active business life has been devoted to important enterprises combining engineering and finance. He took a leading part in the organization and reorganization of the numerous railroads, including the West Shore, Central of New Jersey, Western Maryland and the Northern Pacific. Out of innumerable small companies he created the American Cotton Oil Company, led in establishing the All-America Cables, and has had no unimportant share in many another industrial undertaking. For fifteen years he was a member of the banking firm of Winslow, Lanier & Company, and for twenty-one years American representative of the Deutsche Bank, of Berlin.

Relation of Diesel Electric Locomotive to Electrification

A meeting of great interest in these days of acute transportation problems is to be held jointly by the four Founder Societies, the A. S. C. E., A. I. M. E., A. S. M. E. and A. I. E. E. on Thursday, February 18, 1926, 8 p. m., Engineering Societies Building, 33 West 39th St., New York, N. Y. The subject "The Relation of the Diesel-Electric Locomotive to Electrification" will be developed by three speakers: C. H. Stein, General Manager, Central Railroad of New Jersey; Hart Cooke, McIntosh and Seymour Company; and N. W. Storer, Westinghouse Electric and Manufacturing Company.

Mr. Stein will speak of heavy electrification problems as seen by the operating officials with relation to short bank, switching and terminals, showing how single units with their own power plants might fit, and also supplement trunk line electrification. Mr. Hart Cooke will describe the characteristics of the Diesel-Electric Locomotive and give some results of operation. He will show why and in what way it will as a prime mover meet requirements. Mr. Storer will deal with the electrical characteristics of the Diesel and cover the problem from the standpoint of the electrical engineer and electrical equipment. The meeting will be presided over by H. A. Kidder, Supt. of Motive Power, I. R. T., Chairman, New York Section A. I. E. E. and George J. Ray, Chief Engineer, D. L. & W. R. R., Chairman, New York Section A. S. C. E.

ENGINEERING FOUNDATION

A PLATFORM FOR ENGINEERING FOUNDATION
An Announcement

Engineering advances by continual gain and diffusion of new knowledge. Organizing for effective conduct of research under the auspices of the four national American Societies of Civil, Mining and Metallurgical, Mechanical, and Electrical Engineers, has, however, not been a simple task. Nevertheless, important progress has been made recently.

Technical investigations have been conducted by these Societies severally for years; but there has been little correlation and no comprehensive program. Only within a decade have engineers come to understand research in the same sense as scientists. Ambrose Swasey, by his far-sighted suggestion in 1914 of an engineering research foundation, and a gift for the beginning of its endowment, compelled study of this problem.

Then came the great war and the organizing of scientists and technologists to aid the Government should our country become involved, as in 1916 appeared inevitable. Engineering Foundation assisted, therefore, in establishing National Research Council and cooperated with it through the war and reconstruction. Indeed, it has been said repeatedly that if the Foundation had

accomplished nothing else, this service alone would have justified Mr. Swasey's gift. Scientists and engineers repeatedly gave practical demonstration of the usefulness of research in meeting war emergencies. In peace, also, wisely directed cooperative research can be useful, for it can aid in solving urgent problems, and, besides, add to the store of knowledge on which are based progress in industry, advancement of engineering practise and improvement of technical education, for the greater satisfaction of human needs and desires.

In 1923, Engineering Foundation again found itself facing its primary problem, but with experience accumulated and useful work done. Its Founder Societies in the interval had progressed in research and in development of their organizations and their joint relations. Together they attacked again this problem so important to the profession and the country. Naturally there has been variety in conception of the form and functions of the Foundation and of the relations between it and the Societies. Out of prolonged consideration a plan has emerged which assures progress and achievement. Its fundamentals are embodied in a Platform for Engineering Foundation, adopted at a meeting of its Board December 10, after approval of a draft by the governing body of each Founder Society based on a unanimous recommendation of their Joint Conference Committee, composed of their presidents and secretaries.

Platform for Engineering Foundation

Desiring to promote active and wisely directed research as a means to scientific and technical progress and believing that systematic cooperation by Engineering Foundation and the several Founder Societies is essential to any development of the research work of the Societies commensurate with the dignity, influence and resources of the profession, Engineering Foundation, while reserving entire liberty of action under the authority conferred upon it by the Founder Societies, through United Engineering Society, adopts the following declaration of its present plan and policy:

1. Engineering Foundation regards engineering research as the preferred field for its activities.
2. It will select or approve specific researches which it will assist by appropriation of funds or otherwise.
3. It will select for each project the agency, collective or individual, which it deems most effective.
4. It will assume no direct responsibility for the prosecution of any specific research.
5. It will cooperate with the national Engineering Societies and preferably support researches approved by it sponsored by one or more of them.
6. A member of Engineering Foundation, or of its staff, may be an advisory, but not an active, member of any committee or other organization in immediate charge of a research assisted financially by the Foundation. This provision will not be retroactive.
7. Engineering Foundation reserves the right to require from committees or other organizations or individuals assisted, satisfactory progress reports as a condition of continued support.
8. Engineering Foundation will cooperate with the several Founder or other national Engineering Societies in raising funds for the prosecution of approved researches.
9. It will endeavor to prevent conflict or overlap of research effort among the agencies which it supports or assists.
10. It will cooperate in securing information of the state of the art for use of committees of the Founder Societies or other agencies.

Adoption of this plan has placed the impartial and judicial attitude of Engineering Foundation beyond the questions which, without it nevitably would have arisen when the Foundation in future determined allotment and use of large sums.

Under the policy adopted, researches conducted by the Founder Societies will be doubly safeguarded in their selection, since they will have passed independent approval by the board of a Founder Society and by Engineering Foundation. Likewise, collective wisdom will be exercised in the use of funds entrusted to Engineering Foundation and to the Founder Societies.

A project having been thus endorsed, members of the Founder Society advocating it should be effective, directly or through Engineering Foundation, in raising funds or securing other aid by appeal to those who may expect to benefit.

And the time may not be far distant when the intelligence of those who have benefitted from engineering will perceive the advantage to be derived for the Profession, for Industry and for the Public from providing Engineering Foundation so adequately with funds that effort and time now expended in solicitation, with all the incidental annoyances and waste, may be conserved for earlier attainment of benefits sought.

L. B. STILLWELL, Chairman.
ALFRED D. FLINN, Director,
Engineering Foundation

PERSONNEL RESEARCH FEDERATION

Since 1921, the Personnel Research Federation, according to the fourth annual report, has been gaining support and promoting a number of researches. Since 1922 it has issued the Journal of Personnel Research, recognized not only in America but in other countries as well. Doctor Walter V. Bingham, Director of the Federation, is also editor of the *Journal of Personnel Research.* The Federation has 28 member organizations and 62 individual members, widely distributed. Recent additions to this cooperative membership include the Massachusetts Institute of Technology, Division of Industrial Cooperation and Research; Yale University, Department of Administrative Engineering; the Federal Board of Vocational Education. Officers elected for the current year are President, Howard Coonley, member, American Society of Mechanical Engineers, President, Walworth Company, Boston; Vice Presidents, Alfred D. Flinn, Director, Engineering Foundation, New York; William Green, President American Federation of Labor, Washington; Cator Woolford, Retail Credit Company, Atlanta; Secretary, Robert I. Rees, American Telephone and Telegraph Company, New York; Treasurer, Francis H. Sisson, Vice-President, Guaranty Trust Company New York.

American Engineering Standards Committee

NEW LIMIT-GAGE FOR MASS PRODUCTION

To make for the greatest possible output of the highest quality mass production, has become available to all American manufacturers of machinery, vehicles, tools, electrical apparatus and many other lines of product through the standardization of the limit gages just completed by the American Engineering Standards Committee. The limit gages upon which the new standards are based are simple devices for great accuracy in checking dimensions. The preparation of the standards was the work of a committee of twenty-one experts under the chairmanship of Colonel Eugene C. Peck, prominent manufacturer of Cleveland, Ohio; the committee was under the official leadership of The American Society of Mechanial Engineers. Not only industrial groups but the government, through the Army and Navy Departments and Bureau of Standards participated.

UNIFICATION OF WIRE AND SHEET METAL GAGES PROPOSED

The American Engineering Standards Committee has been requested by the Society of Automotive Engineers to take up the unification of wire and sheet metal gage systems in order to arrive at a national standard system of designating the diameters of metal wires and the thicknesses of metal sheets.

A conference of all industrial groups interested in this problem will be called in the near future, to discuss the desirability and

possibility of unifying the various existing gage systems into a consistent national system, or systems.

CAN AMERICAN AND BRITISH SCREW THREADS BE UNIFIED?

A conference of standardization experts is to be held in April to discuss possibilities. and the American Engineering Standards Committee and the National Screw Thread Commission have invited the British Engineering Standards Association to consider the possibility of unifying the American and British screw thread systems.

Both the American and the British systems of screw threads have been the result of a long national development, the basis for the American system having been laid by William Sellers in 1864, and that for the British system by Joseph Whitworth in 1841. The standard threads are called "American (national) standard thread" in this country, and "British Standard Whitworth (BSW) thread" in Great Britain.

A fundamental difference between the two national systems exists, however, and the importance of a possible unification between the two screw thread systems will be obvious if one realizes the innumerable applications of threaded parts to modern manufacture.

Sharon, Pa., Has New Section

Amid considerable enthusiasm manifested by the 225 who were present a new Section was formally organized at Sharon, Pa., at a meeting held on January 5 and the following Officers were elected and the first Section paper presented: W. M. Dann, Chairman, L. H. Hill, Secretary-Treasurer.

An executive committee consisting of the following members was elected: Chairman, W. M. McConahey, C. S. MacCalla, E. B. Clarke, W. J. Harrier and P. E. Cook.

Power Flow in Electrical Machinery was the title of the paper, presented by Joseph Slepian, Westinghouse Electric & Mfg. Co. Extensive discussion followed the address.

Formation of the Sharon Section brings the total number of Institute Sections up to fifty-one.

New Metallurgical Laboratories

The new metallurgical laboratories of the Pittsburgh Experiment Station of the Bureau of Mines, Department of Commerce, will be formally opened on the evening of January 26. Members of the Metallurgical Advisory Board of Carnegie Institute of Technology and the Bureau of Mines will be present. Others prominent in the mining and metallurgical fields are expected to attend.

The new metallurgical laboratories are the outgrowth of an agreement made in 1923 under which Carnegie Institute of Technology appointed an advisory board for its Department of Metallurgy and arranged for cooperative research fellowships in metallurgy at the Pittsburgh Experiment Station of the Bureau of Mines. Under the arrangement, certain problems in the metallurgy of iron and steel formerly conducted at the Northwest Experiment Station of the Bureau of Mines, Seattle, Wash., are being studied at Pittsburgh. In the study of these problems, the well equipped laboratories of Carnegie Institute of Technology will be available to supplement those of the Bureau of Mines.

Monthly Bulletin of the Mexico Section

The Mexico Section of the Institute started to publish at the beginning of 1924 a monthly Bulletin in the Spanish language, containing not only the proceedings of the Section, but also many other articles and technical papers of interest to electrical engineers.

The Bulletin is mailed free of charge to every electrical and mechanical engineer, every light and power company, and many other companies and individuals in the Republic of Mexico; and the Mexico Section is also willing to mail it to Spanish speaking members of the Institute in other countries, without charge, upon receipt of application.

Letters may be addressed to any of the following: Mr. E. F. Lopez, Fresno No. 111, Mexico, D. F., Chairman, and Mr. Hernan Larralde, Isabel LaCatolica 33, Mexico, D. F., Secretary, Mexico Section; Mr. Jorge E. Castro, Apartado Postal 124 Bis, Mexico, D. F., Editor in Chief, and Mr. J. P. Ramirez, Apartado No. 2057, Business Manager, of the Bulletin.

G. E. Review Plans 5-Year Index

An index of articles run in the magazine during the past five years is being planned by the *General Electric Review*. The index will be alphabetically arranged by subject and author, thus facilitating ready reference to articles carried during the years 1920-1925. It will be bound in a durable, heavy, stock paper cover and will be made to sell for a nominal sum. The size of the index will be 8 by 10½ in.—the same as the magazine.

Before starting the work of compiling this information, the *Review* is anxious to secure the comments of libraries and individuals interested in such a publication. It is requested that those who can make use of the index signify their interest in it by writing the magazine at Schenectady, N. Y. If sufficient interest is manifested in the work, it will be started within a few weeks.

National Academy of Sciences Appeals For Research Funds

The National Academy of Sciences announces an appeal to prominent public men to join with the leading scientists of the country in an endeavor to secure greater resources for the research in pure science, claiming that while the United States is leading all nations in industrial science, it is falling behind in pure science research. A special board created by the Academy for the handling of these funds includes Albert A. Michelson, President of the National Academy of Sciences and a Nobel prize winner; Gano Dunn, chairman of the National Research Council; Vernon Kellogg, Permanent secretary for the National Research Council; Elihu Root, Herbert Hoover, Andrew W. Mellon, Charles E. Hughes, John W. Davis, Colonel Edward M. House, Julius Rosenwald, Cameron Forbes, Felix Warburg, Henry S. Pritchett, Doctor Robert Millikan, Foreign secretary of the National Academy of Sciences, Doctor Merriam of Carnegie Institution of Washington, Owen D. Young, Henry M. Robinson, Doctor Simon Flexner of the Rockefeller Institute of Medical Research, Doctor J. J. Carty, Vice-President of the Am. Tel. & Tel. Co. and past-president of the A. I. E. E., Doctor Wm. H. Welch, Director of the School of Hygiene and Public Health, Johns Hopkins University and others of equal prominence.

PERSONAL MENTION

William S. Schmidt will shortly join the Pennsylvania-Ohio Power & Light Company at Youngstown, Ohio. Mr. Schmidt has been connected with the Penn Public Service Corporation for the past few years.

Rene A. Wurgel who has been planning engineer for the Western Electric Company New York City, has accepted a position as Purchasing Engineer with the Holly Pneumatic Systems, Inc., 100 East 45th Street, New York City.

Edgar Kobak has been elected vice-president and director of the McGraw-Hill Company, Inc., acting as publishing head of the McGraw-Hill electrical publications, *Electrical World*, *Electrical Merchandising*, *Industrial Engineer*, *Journal of Electricity and Radio Retailing*.

Frank A. Ketcham will be executive vice-president of the new Graybar Electric Company. Mr. Ketcham has been with the Western Electric Company for the past eighteen years, beginning as a clerk in their Chicago office. Since 1921, he has held the position of general manager of their supply department.

A. W. McLimont has been appointed president of the Winnipeg Electric Company for which he has served as vice-president and general manager for the past eight years. Mr. McLimont was formerly electrical engineer of the First District of the Public Service Commission of New York and has been connected with electric systems in both South America and Mexico.

C. M. Goddard, for thirty-five years secretary of the New England Insurance Exchange, was given a dinner on January 7th by 200 of his associates in the fire insurance field. Mr. Goddard was closely associated with the development of the National Electrical Code retiring from active business on the first of this year.

Theodore H. Dillon, professor of public utility management at Harvard University, has resigned to become manager of the Boston district of the United Fruit Company. Colonel Dillon was for several years professor of electrical engineering at Massachusetts Institute of Technology and is a graduate of West Point, holding a record for distinguished military engineering.

W. H. Sawyer, Fellow of the A. I. E. E. and H. W. Eales, a regional vice-president of the A. I. E. E., sail for Australia on February 2nd to make a report of investigation on the Yallourn brown coal electricity generation scheme and connected power undertakings of the government electricity commission. Their chief mission is to place the benefit of America's electrical experience at the disposal of Australia.

Donald McNicol, Fellow of the A. I. E. E. and last year assistant to the president of the Radio Corporation of America, has been elected president of the Institute of Radio Engineers, taking office at the time of their recent convention held in the Engineering Societies Building January 18-19. Good progress in this specific field of scientific endeavor seems assured both by the success of this, the first full membership convention of the Radio Engineers and in their choice of Mr. McNicol as president for the ensuing year.

William K. Vanderpoel, since January 1, 1916 general superintendent of distribution, of what is now the Electric Department of Public Service Electric and Gas Company has resigned to become vice-president and executive engineer of The Okonite Company and The Okonite-Callender Cable Co., Inc., manufacturers of wire and cable for electric purposes, with factories at Paterson and Passaic, and general offices in New York City. Mr. Vanderpoel came to Public Service in 1907 as superintendent of Distribution for the Newark district, and in 1916 was made general superintendent of distribution. He is a Director of the A. I. E. E. and has served, or is serving on its Executive, Finance, Power, Standards, Edison Medal committees and others.

S. L. Nicholson has recently been elected acting vice-president of the Westinghouse Electric and Manufacturing Company. Mr. Nicholson has been affiliated with the Westinghouse Company since 1898, being appointed sales manager in 1909 and assistant to the vice-president in 1917. He was the first president of the American Association of Electric Motor Manufacturers, now known as the Electric Power Club, assisted in the formation of the American Gear Manufacturers' Association, was chairman of the Power Club, Electric Manufacturers' Club and the Association of American Manufacturers of Electrical Supplies. During 1921, Mr. Nicholson was chairman of the Tariff Committee of the Council and represented the electrical industry on the National Industry Conference Board: is a member of the Electrical Safety Conference, the American Statistical Association and the Bureau of Personnel Research for Carnegie Institute of Technology.

Addresses Wanted

A list of names of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th St., New York, N. Y.

All members are urged to notify the Institute Headquarters promptly of any change in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—Geo. B. Coleman, P. O. Box 322, Dayton, Ohio.
2.—Geo. E. Haines, 3538 W. Monroe St., Chicago, Ill.

Obituary

Loyal B. Alden, construction engineer, died on December 13, 1925. Mr. Alden was born in 1870 in Leicester, Addison County, Vermont. He received his engineering education at the Massachusetts Institute of Technology—later taking the student's course in the Construction Department of the General Electric Company. He was connected with the General Electric Company in Baltimore for some years, having been in charge of the construction of a transformer station in Baltimore, built in connection with the McCall's Ferry Plant and the substation of the Baltimore and Ohio Railroad on Park Avenue which furnishes current for running the Belt Line Railroad of the Baltimore & Ohio Railroad Company.

Arthur W. Jones died at his home in Schenectady, December 26, 1925. Mr. Jones was born in Philadelphia in May 1866 and took an electrical engineering course at the Massachusetts Institute of Technology—after graduation he officiated with the Thomson-Houston Company of Lynn, Mass. Several years later became chief engineer of the International Thomson-Houston Company. In 1894 he was sent to Port Elizabeth, South Africa, and as representative of the General Electric Company for that territory, in 1895 accepted a similar position in Melbourne, Australia. Returning to Schenectady in 1905, he served as manager of the railway signal department—being directly connected with the Far East department of the International General Electric Company and having direction over the company's interests in various Oriental Countries.

Otto C. Miller, of the Los Angeles Section of the Institute, died on December 11, 1925, in that city. He was born in Columbus, Texas, on September 12, 1867 and received his education as private student and co-worker with William Lundberg, a Danish mathematician and scientist in Los Angeles. Mr. Miller has been connected with the Los Angeles Gas and Electric Corporation for the past fifteen years as an Electrical Underground Engineer.

Benjamin H. Ryder, a member of the A. I. E. E., died on December 28, 1925. Mr. Ryder's birth place was Hudson, N. Y., where he was born December 3rd, 1878. He received his education in Chicago, becoming connected with the American Steel & Wire Company in Pittsburgh shortly thereafter. Later he was transferred to the Chicago office of the concern, where he remained until the time of his death. Mr Ryder's loss will be felt by his many friends and associates.

Frederick A. Huntress, for many years an official of the Brazilian Traction, Light and Power Company, Ltd., operating in the city of Rio Janeiro and Sao Paulo, Brazil, died January 27th at his apartment, Hotel Somerset, Boston.

Born in Biddeford, Maine, Mr. Huntress' late general and technical education was through Harvard College, from which he graduated in 1891 with the degree of A. B. In 1893, he affiliated himself with the Boston Elevated Railway, doing special work in

generation and distribution of power for them. In 1894 he was identified with the Montreal (Canada) Street Railway Company as assistant to the Electrical Engineer, to return in 1895 to the Boston Elevated Railway as assistant to their master mechanic. In 1896 he was made assistant to the general manager of the Halifax Tramway Light and Power Company, and later became general manager himself in 1898. In 1903, the Worcester Consolidated Street Railway Company chose him as their general manager and he remained with them until his departure from the States to connect with the Rio Janiero Tramway Company of which he was first Vice President at the time of his death. In 1922 he returned from South America to take residence in Lenox, Mass., and has remained in the United States ever since.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES DECEMBER 1-31, 1925

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statement made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

AUFGABENSAMMLUNG UBER DIE GLIECHSTROMMASCHINE MIT LOSUNGEN.

By Fr. Sallinger. Ber. u. Lpz , Walter de Gruyter & Co., 1925. 108 pp., diagrs., 6 x 4 in., cloth. 1,25 gm.

This, the third volume of Professor Sallinger's concise text-book on continuous-current machines, is devoted to examples of the application of the formulas and rules given in the previous volumes. These examples are worked out in detail and illustrate clearly the practical use of the theory.

ELEMENTS OF INTERNAL-COMBUSTION ENGINEERING.

By Telford Petrie. Lond. & N. Y., Longmans, Green & Co., 1925. 236 pp., diagrs., 9 x 6 in., cloth. $3.75.

The various types of gas and oil engines, their cycles of operation, ideal cycles and their functions, the thermodynamics of the gas engine and the other theoretical considerations of these engines are discussed. The work is confined to theory and does not discuss practical details of design.

L'EMPLOI DES INDICATEURS COLORES; LA DETERMINATION COLORIMETRIQUE DE LA CONCENTRATION DES IONS HYDROGENE.

By I. M. Kolthoff. Translated from the 3rd German edition by Edmond Vellinger. Paris, Gauthier-Villars et cie, 1926. 250 pp., diagrs., tables, 9 x 6 in., paper. 50 fr.

The simplicity and rapidity of the color indicator method of measuring the concentration of hydrogen ions in aqueous solutions have led to a wide extension of its use for this important purpose. The author of this book gives a survey of the various methods used and studies their application under a wide variety of conditions, so that the work is of value to all who utilize indicators in chemical or biological work.

HEALTH MAINTENANCE IN INDUSTRY.

By J. D. Hackett. Chicago & N. Y., A. W. Shaw Co., 1925. 488 pp., diagrs., tables, 9 x 6 in., fabrikoid. $6.00.

Increasing appreciation of the relation between the health of workmen and their efficiency has led to the establishment of medical departments in many plants. This book gives an account of the organization of such a department and of the ways in which it may aid production. The subject is treated simply, from the point of view of the plant manager, who is responsible for the direction of the activities of the department, but has no medical training.

HEPHAESTUS; OR, THE SOUL OF THE MACHINE.

By E. E. Fournier D'Albe. N. Y., E. P. Dutton & Co., 1925. 76 pp., 7 x 5 in., cloth. $1.00.

An interesting, original study of the relations between man and his machines. How the age of machinery has come about and what influence machinery will eventually have on society is explained in striking fashion in this little book.

INDUSTRIAL ELECTRICITY, Part 2.

By Chester L. Dawes. N. Y., McGraw-Hill Co., 1925. (Electrical Engineering Texts) 480 pp., illus., diagrs., 8 x 6 in., cloth. $2.75.

D-c. machinery having been covered in the first volume of this text, the present book takes up alternators. The fundamental principles and the simple laws of alternating currents and a-c. circuits fill the first chapters. The construction and operating characteristics of a-c. generators and motors are then discussed and analyzed, and the relations of their characteristics to their industrial uses considered. The last three chapters are devoted to general industrial applications of electricity, such as illumination, electron emission and radio communication.

INDUSTRIAL FURNACES, Vol. 2.

By W. Trinks. N. Y., John Wiley & Sons, 1925. 405 pp., illus., diagrs., tables, 9 x 6 in., cloth. $5.50.

While the first volume of this important work was largely theoretical and of particular interest to the designer, this volume is primarily devoted to practise and makes its appeal to those who select, install and operate furnace equipment. The author discusses fuels, combustion devices, temperature control, atmosphere control and labor-saving devices, compares various fuels and types of furnaces, and offers advice on their selection. Electric furnaces are included in the discussion.

L'INDUSTRIE CHIMIQUE DES BOIS; leurs dérivés et extraits industriels.

By P. Dumesny and J. Noyer. Paris, Gauthier-Villars & cie., [1925.] 432 pp., illus., diagrs., 10 x 7 in., paper. 50 fr.

In writing this book, the authors have had in mind the needs of practical men and have given special attention to industrial methods. The book is divided into two sections. The first opens with a review of the chemical composition of wood and the properties of the products obtained by carbonization and by distillation. The principal processes of carbonization are then described. A chapter is devoted to the manufacture of acetic acid, methyl alcohol and the acetates, and another to secondary products of wood distillation. The second section treats of the extraction and use of tannins.

JAHRBUCH DER BRENNKRAFTTECHNISCHEN GESELLSCHAFT.

E. V. 1924. V. 5. Halle (Saale), Wilhelm Knapp, 1925. 112 pp., illus., diagrs., 11 x 8 in., paper. 7,80 gm.

The fifth yearbook of the Society includes a report of the proceedings at the annual meeting of December, 1924, and several of the papers read at that time. These include addresses on "Internal Combustion Engines, Especially Diesel Locomotives for Railways" by H. Nordmann; "Ignition Phenomena in Gas Engines" by J. Tausz; "Large Diesel Engines for Ships" by R. Dreves; "Raising the Power of Gas Engines through Pre-compression by Blowers, and the Use of Exhaust Gases in Turbines to Drive these Blowers" by W. G. Noack; "The Principles of High-Speed Semi-Diesel Engines" by Dr. Büchner; and "On the Numerical Expression of the Idea of the Quality Calorie" by W. Ostwald.

DIE LEISTUNG DES DREHSTROMOFENS.

By J. Wotschke. Berlin, Julius Springer, 1925. 70 pp., diagrs., tables, 9 x 6 in., paper. 5,10 g. m.

Books on the electric furnace are not numerous, and in those that exist less attention is paid to the needs of the electrical engineer than of the chemist and metallurgist. In this book the author attempts to meet electrical requirements by a discussion of the electrical theory and of the electrical factors that make for the greatest efficiency. He calls attention to opportunities for research in this field.

NIAGARA IN POLITICS; a Critical Account of the Ontario Hydro-Electric Commission.

By James Mavor. N. Y., E. P. Dutton & Co., 1925. 255 pp., 8 x 5 in., cloth. $2.00.

Professor Mavor's work is an indictment of the Hydroelectric Power Commission of Ontario, which he condemns on grounds of both public policy and of economic advantage.

PATENTS; Law and Practice. 3rd edition. 1924. 56 pp.

TRADE-MARKS, TRADE NAMES, UNFAIR COMPETITION. 4th edition. 1925. 48 pp.

N. Y., Richards & Geier, 277 Broadway. 9 x 6 in., paper. Gratis.

These pamphlets provide a convenient summary of the patent and trade-mark laws of the principal countries of the world. They are intended to give laymen the more important facts, as a guide in meeting the problems that arise most frequently.

POWER PLANT LUBRICATION.

By William Farrand Osborne. N. Y., McGraw-Hill Book Co., 1925. 275 pp., illus., diagrs., tables, 8 x 6 in., cloth. $3.00.

A concise account of the properties of lubricants and of the methods of buying, testing and using them on various classes of power-plant machinery. Intended for operating engineers.

PRACTICAL MARINE DIESEL ENGINEERING.

By Louis R. Ford. N. Y., Simmons-Boardman Publ. Co., 1925. 512 pp., illus., diagrs., 9 x 6 in., fabrikoid. $7.50.

Discusses the theoretical principles of the Diesel engine, the construction of its various stationary and moving parts, and its accessories. Descriptions of typical commercial engines of various types are given, and a large part of the book is devoted to the operation of Diesel engines and the derangements likely to occur. The book is intended for practical enginemen, especially for the marine steam engineers who wish to operate these engines.

STAUB-EXPLOSIONEN.

By Paul Beyersdorfer. Dresden u. Lpz., Theodor Steinkopff, 1925. 125 pp., illus., tables, 9 x 6 in., paper. 5,50 mk.

A summary of our knowledge of dust explosions. Discusses their character, the dangerous properties of dust, effects of heat and static electricity, the action of explosions and methods of prevention. The book is intended to present the situation in a form convenient for consultation by those engaged in dusty industries.

TAGUNG DES ALLGEMEINEN VERBANDES DER DEUTSCHEN DAMPFKESSEL-UBERWACHUNGSVEREINE.

April 1925, Karlsruhe. Berlin, VDI Verlag, 1925. 132 pp., illus., diagrs., plates, 12 x 9 in., paper. 16,-gm.

The proceedings contain reports and discussions upon a number of important matters relating to boiler operation. Among these are the tension in heavy boiler plates; the influence of temperature, shape of test-piece and speed of testing upon notched bar tests; American rules for water purifier operation; accessories for high-pressure boilers; autogenous and electric welding for boiler parts; the high-pressure boiler. Statistics of boilers are appended.

USINES HYDROELECTRIQUES.

By Charles L. Duval and J. L. Routin. Paris, J. B. Baillière et fils, 1925. 512 pp., illus., diagrs., 9 x 6 in., paper. 60 fr.

A general textbook on hydroelectric power plants. The authors give a description of these plants as a whole, showing the various apparatus used and explaining the reasons that have led to its choice in each case, its dimensions and its use. Both hydraulic and electric features are discussed, but details of the construction of the apparatus are omitted.

The book is based on the course at the Ecole Supérieure d'Electricité.

Book Review

SUPERPOWER: ITS GENESIS AND FUTURE.

William S. Murray, New York. McGraw-Hill Book Co. 1925. 238 pp., illus., 6 by 9 in. cloth. $3.00.

In this book Mr. Murray, the father of Superpower, tells in an intimate and pleasingly spontaneous way the complete story of Superpower and its possibilities, from the time he first conceived the idea up to its present development, and its future possibilities. It is pointed out that the name, Superpower, has been frequently misunderstood or misrepresented whereas its real meaning is the physical interconnection of all generating plants within certain zones in order to take advantage of diversity economy and thereby greatly reduce reserve equipment and avail interruptions to service from breakdowns. The subject is discussed from a wide variety of aspects and in non-technical language and points out why this movement, already under way, cannot but eventually furnish more adequate and economic means of power and transportation, which are the two essential elements upon which the industry and prosperity of the nation depend.

Past Section and Branch Meetings

SECTION MEETINGS

Akron

Sleeve Bearings Versus Anti-Friction Bearings, by J. L. Brown, H. D. Else and L. E. Erickson. A dinner preceded the meeting. Joint with A. S. M. E. December 18. Attendance 54.

Baltimore

Dielectrics and Insulation, by J. B. Whitehead, Johns Hopkins University. October 16. Attendance 85.

Holtwood Steam Station, by V. E. Alden, Consolidated Gas, Electric Light and Power Co.

Recent Experience with Transmission System of Pennsylvania Water Power Company, by A. F. Bang and E. Hansson, Pennsylvania Water and Power Co., and

Hydraulic Maintenance at Holtwood Plant, by T. C. Stabley. November 21. Attendance 280.

Electric Refrigeration, by Mr. Twilley, The Kelvinator Co., and

Illumination, by J. C. Fisher, Consolidated Gas and Electric Co. Ladies Night. December 18. Attendance 140.

Chicago

Power Flow in Electrical Machines, by Joseph Slepian, Westinghouse Elec. & Mfg. Co. January 11. Attendance 210.

Cleveland

Railroad Electrification—Present and Future, by N. W. Storer, Westinghouse Elec. & Mfg. Co. Illustrated with slides. November 20. Attendance 91.

Tendencies in Power Development and Transmission, by Robert Treat. Dean C. Ober, Cleveland Electric Illu-

minating Co., showed pictures of new apparatus used in his company's high-tension lines. December 17. Attendance 87.

Denver

Public Utility Securities and Financing, by J. E. Loiseau, Public Service Company. December 18. Attendance 27.

Detroit-Ann Arbor

Recent Developments in Heavy Electric Traction, by N. W. Storer, Westinghouse Elec. & Mfg. Co. A motion picture, entitled "Electrified Travelogue," preceded the talk. November 17. Attendance 100.

Polarization of Radio Waves, by E. F. W. Alexanderson, Radio Corporation of America. A motion picture, entitled "The Story of the Storage Battery," preceded the talk. December 4. Attendance 450.

Erie

Radio, by P. J. Larsen, Radio Corporation of America. The lecture was illustrated with moving pictures and the latest a-c. receiving sets and loud speakers were demonstrated. December 15. Attendance 255.

Fort Wayne

Lightning, by F. W. Peek, Jr. December 15. Attendance 80.

Electrons and Hobbies, by W. R. Whitney, General Electric Co. January 11. Attendance 150.

Ithaca

Electrical Transmission of Speech, Music and Noise, by Harvey Fletcher, Bell Telephone System Laboratories. The lecture was demonstrated with special wave-filter apparatus. December 7. Attendance 200.

Los Angeles

Electrolysis, by I. D. Van Giesen, Los Angeles Bureau of Water Works and Supply. Illustrated with slides. A dinner preceded the meeting, at which talks were given by E. A. Bailie, Los Angeles Engineering Dept., and J. E. Philips, Los Angeles Water Distribution Dept., on "The Proposed Colorado River, Los Angeles Aqueduct" and "The Existing Local Water Situation in Los Angeles," respectively. January 5. Attendance 134.

Lynn

The Quest of the Unknown, by H. B. Smith, Worcester Polytechnic Institute. Illustrated with slides. December 17. Attendance 50.

Mexico

Annual Banquet. October 24. Attendance 43.

Parasite Currents in the Bearings of A-C Machinery, by A. Cornejo.

Operation of Distributing Systems of Electrical Energy, by J. V. Crotte. December 3. Attendance 24.

Milwaukee

Design and Construction of the New Riverside Pumping Station, by Ralph Cahill. December 16. Attendance 60.

Minnesota

Communication Service on Railroads, by J. C. Rankine, Great Northern Railway Co. The talk was demonstrated by special telegraph equipment and apparatus. Motion pictures taken along the Great Northern Railway were shown. January 4. Attendance 37.

Nebraska

Automatic Stations, by C. W. Place, General Electric Co. Joint meeting with Engineers Club. December 14. Attendance 78.

Niagara Frontier

The Klydonograph, by J. F. Peters, Westinghouse Elec. & Mfg. Co. January 8. Attendance 35.

Philadelphia

High-Quality Phonographic Reproduction, by J. P. Maxfield, Bell Telephone Laboratories, Inc. December 14. Attendance 315.

Pittsburgh

Breakdown of Solid Dielectrics, by Vladimir Karapetoff, Cornell University. December 8. Attendance 348.

Pittsfield

Electrical Measurements in Medical Diagnosis, by H. B. Williams, Columbia University. December 15. Attendance 260.

Recent Theories and Developments in the Science of Radio, by E. F. W. Alexanderson, Radio Corporation of America. January 5. Attendance 375.

Portland

Baker River Hydroelectric Development, by L. M. Robinson, Stone and Webster, Inc. December 9. Attendance 81.

Providence

Costs of Operation of Isolated Power Plants, by R. L. Yates, Skinner Engine Co. Joint meeting with A. S. M. E., Providence Engineering Society and Illuminating Engineering Society. January 5. Attendance 100.

Rochester

Development and Research Work of the Bell Telephone Laboratories, by S. P. Grace, Bell Telephone Laboratories. December 4. Attendance 300.

San Francisco

Symposium on Power-Distribution Systems, by S. J. Lisberger, G. H. Hager, L. J. Moore and D. K. Blake. A dinner preceded the meeting. October 2. Attendance 190.

Oil Circuit Breakers, by J. S. Thompson, Pacific Elec. Mfg. Co. A dinner preceded the meeting. October 30. Attendance 215.

Some Engineering Aspects of the Telephone Building, by C. W. Burkett, G. M. Simonson and L. W. Whitton. December 11. Attendance 250.

Spokane

Reflections on Power Factor, by W. T. Ryan, Washington Water Power Co. December 18. Attendance 18.

Springfield

Storage Batteries, by R. D. Harrington, Electric Storage Battery Co. December 21. Attendance 47.

Syracuse

Hydroelectric Developments in Japan, by S. Q. Hayes, Westinghouse Electric & Mfg. Co. Illustrated with slides. December 14. Attendance 100.

Toronto

The Chronograph Method of Speed Measurement, by P. A. Borden, Hydro-Electric Power Commission of Ontario. Illustrated. Mr. F. K. D'Alton also gave a short talk on this same subject. Two moving pictures on the "Wizardy of Electricity" were shown by Mr. Johnston of the Canadian General Electric Co. December 18. Attendance 45.

Urbana

A Message from Herbert Hoover, by W. A. Durgin, Commonwealth Edison Co. December 9. Attendance 44.

Mechanical Force between Electric Circuits, by R. E. Doherty, General Electric Co. December 17. Attendance 108.

Worcester

Lightning and Other Transients on Transmission Lines, by F. W. Peek, Jr., General Electric Co. Illustrated with slides and moving pictures. December 10. Attendance 50.

BRANCH MEETINGS

University of Alabama

The meeting was devoted to the showing of moving pictures. December 15. Attendance 36.

University of Arizona

Railroad Electrification, by Charles Dunn, and

Electrification of Ships, by Leo Wolfson. November 7. Attendance 13.

Electrically Driven Vehicles, by Wm. R. Brownlee, and

Electric Welding, by E. Brooks. November 14. Attendance 14.

The Electron Theory, by T. E. Davis. November 21. Attendance 16.

Opportunities in the Telephone Industry. A motion picture, entitled "Rolling Steel by Electricity," was shown. December 5. Attendance 23.

The Big Creek Project, by Jos. Denzer. Moving picture, entitled "Speeding Up the Deep-Sea Cables," was shown. December 12. Attendance 20.

A motion picture, entitled "Beyond the Microscope," was shown. December 19. Attendance 17.

Brooklyn Polytechnic Institute

Engineering Features of Long-Distance Telephony, by C. S. Hawkins, American Telephone & Telegraph Co. Illustrated with slides, and

High-Frequency Radio Oscillations, by B. Adler, student. December 16. Attendance 55.

Carnegie Institute of Technology

Electrification of the Norfolk and Western Railroad, by Thomas Wurts, Westinghouse Electric & Mfg. Co. December 2. Attendance 34.

Case School of Applied Science

Business Meeting. The following officers were elected: Chairman, C. A. Baldwin; Vice-Chairman, E. W. Drexler; Secretary, A. B. Anderson; Treasurer, J. C. Erickson. October 19. Attendance 30.

University of Cincinnati

Relation of the Technical Journal to the Industry, by Earl W. Whitehorne, Commercial Editor of *Electrical World*. December 3. Attendance 59.

University of Denver

Business Meeting. January 8. Attendance 15.

Georgia School of Technology

Business Meeting. December 15. Attendance 40.

Inspection trip to Boulevard Sub-Station of the Georgia Railway and Power Company. December 17. Attendance 35.

University of Idaho

Film, entitled "Pillars of Salt," was shown. December 8. Attendance 24.

State University of Iowa

A film, entitled "The Story of an Electric Meter," was shown. December 18. Attendance 50.

Unipolar Generators, by Herman Wacker, and

Electrons and Ions, by L. A. Ware. January 6. Attendance 44.

Kansas State College

Opportunities of the Graduate, by Professor C. E. Reid. December 14. Attendance 83.

Lehigh University

Making the Most of Opportunities, by H. P. Liversidge, Philadelphia Electric Co., and

Automatic Train Control, by O. M. Corson, student. December 17. Attendance 89

Lewis Institute of Technology

Business Meeting. December 10. Attendance 11.

Marquette University

Picking a Job, by F. J. Mayer, Wisconsin Telephone Co. October 15. Attendance 29.

Super-Power, by G. G. Post, Milwaukee Electric Railway & Light Co. November 19. Attendance 28.

Massachusetts Institute of Technology

The M. I. T. Power System, by Theodore Taylor, student. Illustrated with slides. December 15. Attendance 18.

Inspection trip to the Cambridge Plant of the Simplex Wire and Cable Company. December 16. Attendance 5.

University of Michigan

Smoker. December 9. Attendance 65.

School of Engineering of Milwaukee

Industrial Management, by E. E. Brinkman, Holeproof Hosiery Company. January 7. Attendance 28.

Missouri School of Mines and Metallurgy

A general discussion on motor windings, synchronous motors, advantages of their use, and power transmissions took place. January 7. Attendance 10.

Montana State College

Lightning Generators, by Sam Thompson, and

Advantages of Electric Traction, by Rudolph Scovil. December 14. Attendance 159.

College of the City of New York

What the Designing Engineer Has to Do in Practise, by E. S. Henningsen, General Electric Co. January 14. Attendance 24.

University of North Carolina

A Supersensitive Microphone and Its Application to Surgery, by J. F. Clemenger, student. December 4. Attendance 26.

University of North Dakota

Asbestos, by H. G. Thinnes, Johns-Manville, Inc. Demonstrated. A motion picture, entitled "The Story of Asbestos," was shown. Joint meeting with A. S. M. E. December 14. Attendance 5.

Northeastern University

The Work of a Public-Utility Electrical Laboratory, by H. C. Hamilton, Edison Electric Illuminating Co. Illustrated with slides. December 30. Attendance 34.

University of Notre Dame

The Theory of Electricity, by Malcolm Knaus, and

The Fourth Dimension, by Dr. J. A. Caparo. December 9. Attendance 37.

Oklahoma Agricultural and Mechanical College

Two moving pictures, entitled "Electrified Travelogues" and "The King of the Rails," were shown. December 17. Attendance 48.

University of Oklahoma

Three moving pictures, entitled respectively, "King of the Rails," "Big Deeds" and "The Manufacture of Paper," were shown. December 10. Attendance 107.

University of Pittsburgh

Transmission Design, by T. E. Baum, student,

"B"-Battery Eliminator, by N. Orr, student, and

Photo-Electric Cells, by W. D. Carothers, student. December 4. Attendance 22.

The Measurement of Earth Currents, by J. A. Balla, student, and

The Allegheny Bridge Problem, by Chas. M. Reppert, Dept. of Public Works, and V. R. Covell, Bureau of Bridges. December 10. Attendance 25.

The Transmission of Vision and Radio Broadcasting, by H. I. Metz, student. December 17. Attendance 28.

Purdue University

Shaft Behavior, by Dr. G. E. Newkirk, General Electric Co. Joint meeting with A. S. M. E. December 17. Attendance 60.

Rensselaer Polytechnic Institute

What We can Learn from Technical Education in Europe, by C. E. Wickenden, Society for the Promotion of Engineering Education. December 9. Attendance 385.

Rhode Island State College

A moving picture, entitled "From Mine to Consumer," was shown. January 7. Attendance 27.

Rose Polytechnic Institute

The Student Course with the Westinghouse Company, by R. H. Bolin, Westinghouse Electric & Mfg. Co. January 6. Attendance 43.

Rutgers University

The Giant Power System was the title of a debate held at this meeting. December 14. Attendance 24.

A moving picture, entitled "The Story of Copper from Mine to Consumer," was shown. January 11. Attendance 105.

South Dakota State School of Mines

Business Meeting. December 16. Attendance 12.

Business Meeting. January 8. Attendance 18.

University of South Dakota

Business Meeting. October 13. Attendance 15.

What is Matter? by M. Nelles, and

Production of High-Frequency Oscillations, by R. Brackett. November 10. Attendance 9.

Progress of Science, by Dr. Millikan, was read by A. Muchow, and

Wind-Mill Electric Power for the Farm, by W. Doohen. December 8. Attendance 9.

Swarthmore College

The Steel Industry, by Mr. Munson, Atlantic Steel Co. January 7. Attendance 40.

Syracuse University

A-C Railway Electrification, by C. R. Fugill. December 2. Attendance 20.

Lightning Arresters, by R. M. Kelly. December 9. Attendance 18.

Types of Relays and Their Application, by W. H. Lawrence. December 16. Attendance 19.

Texas Agricultural and Mechanical College

Two moving pictures, entitled "Manufacture of Paper" and "Wireless Wizardy," were shown. January 8. Attendance 71.

Washington University

Inspection trip to United Railway Company's Two-Unit Automatic Substation. November 27. Attendance 35.

The Engineering Profession, by Mr. Trescott, Commercial Electric Supply Co. December 3. Attendance 28.

University of Washington

Products of the Northwest, by R. W. Frame, Kenworth Motor Truck Co., and *The Development of the Railroad*, by G. T. Reid, Northern Pacific Railroad Co. December 2. Attendance 125.

University of Wisconsin

The Panama Exposition, by Professor C. M. Jansky. Illustrated with slides. December 15. Attendance 64.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers cooperating with the Western Society of Engineers. The service is available only to their membership, and is maintained as a cooperative bureau by contributions from the societies and their individual members who are directly benefited.

Offices:—33 West 39th St., New York, N. Y.,—W. V. Brown, Manager.
53 West Jackson Blv'de., Room 1736, Chicago, Ill., A. K. Krauser, Manager.

MEN AVAILABLE.—Brief announcements will be published without charge but will not be repeated except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City,*** *and should be received prior to the 15th of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

DESIGNER, for manufacturing purposes of such equipment as air break switches, gang operated disconnect switches, bus supports, etc. Experience in simple station operation, design of substations, etc., does not qualify a man for this position. Experience in the actual design and manufacture of the class of equipment described essential. Location, Pennsylvania. R-8118-C.

ENGINEER, experienced in selling industrial electric heating furnaces, for manufacturing concern. Apply by letter stating age, experience and education. Location, Pennsylvania. R-8328-C.

ENGINEER, with experience in design and installation of power station switching equipment. Must be able to supervise and make schematic diagrams of station layout drawings. This is not a drafting job, but requires design ability. Permanent. Opportunity. Apply by letter. Location, Pennsylvania. R-8530-C.

ELECTRICAL ENGINEER, particularly interested and experienced in relay and breaker applications and protection problems on larger power systems. Location, Pennsylvania. R-8506.

ELECTRICAL ENGINEER, experienced in design and calculation of small high tension transformers both closed and open core type. Salary $4000-$5000 a year. Location, New York. R-8346.

ENGINEER, to develop new grinding machines line, especially versed in electrical and hydraulic application. Must have had practical shop training and particularly a thorough scientific and technical education. Apply by letter. Location, Ohio. R-8396-C.

MEN AVAILABLE

GRADUATE ELECTRICAL ENGINEER, age 25, married, desires position with electrical manufacturer or public utility company. Westinghouse experience. Location, East or Middlewest. B-9508.

ELECTRICAL ENGINEER, age 37, college graduate, eighteen years' experience, G. E. test course, system operation, operation, maintenance, construction, design of steam and hydroelectric plants and substations. Just completed three year connection involving design, erection and operation of large high head hydro electric plant. Desires permanent position. Available now. A-895.

ELECTRICAL ENGINEER, 26, six years iron and steel works electrical plant, installation, layout and maintenance both A. C. and D. C., three years manufacturing works, test, design and construction of industrial electrical plant, two years oil fields electrical construction engineer. Desires position either construction or maintenance of power plant, factory, oil fields or iron and steel works. C-8625.

EDITOR OR STATISTICAL ENGINEER, general scientific and electrical engineering training, including two years' post graduate study. Broad experience writing, editing magazine articles, newspaper articles, booklets, books, advertising literature, etc. Thorough knowledge printing. Experience statistical work, sales promotion, business administration, business efficiency methods as assistant to prominent executive large corporation. Location, New York City, Chicago, or Boston. C-549.

ELECTRICAL ENGINEER, age 28, single, technical graduate, desires position with manufacturer electrical apparatus. Five years' experience with engineering department of large company manufacturing industrial control equipment. A little sales experience. Minimum salary $2500. Available on reasonable notice. B-6274.

ELECTRICAL-MECHANICAL ENGINEER, age 37, married, M. E. and E. E. degrees, experienced in design, installation, operation, rehabilitation of hydroelectric and steam power plants, automatic and manual substations, transmission lines underground and overhead, diversified industrial experience in sugar mills, paper mills, mining (gold and coal), public utility, marine engineering and machine shop manufacturing processes. Location anywhere, United States or Canada. B-7944

MECHANICAL ENGINEER, age 32, single, nine years' experience in electrical and mechanical engineering. Electric lighting and power distribution, motors and control, for industrial use. Design of boiler plants, heating and piping. Machinery layouts for plants. Can report at once. Northern part of United States preferred B-3103.

ELECTRICAL ENGINEERING GRADUATE, 1917, age 29, single, desires construction, operation or maintenance with public utility, or consulting engineer; design, research, teaching also considered. Two years Westinghouse student and tester. Some radio, electrical drafting and repair work. Now in fifth year as assistant in E. E. in large Middlewest state university teaching design and power plant economics. M. S. degree 1925. Available in June. Salary $200 per month. B-2758.

ELECTRICAL ENGINEER, age 27, research, in charge of electrical testing, three years chief draftsman; inventive, tactful. Desires responsible position with manufacturing concern. Greater New York preferred. Best references. At present employed. Available on two weeks' notice. B-7270.

MANAGER - GENERAL SUPERINTENDENT-SALES ENGINEER, age 44, unmarried, degree Ph. B in E. E., twelve years with Westinghouse, ten years in utility field. Design, construction, operation four utilities in United States, Alaska, British Columbia. Available at once. B-6910.

MANUFACTURERS' REPRESENTATIVE, located in Sydney, N. S. W., Australia, desires additional agencies for American products of electrical and mechanical nature. Technical training, experience, knowledge of conditions. C-798.

ELECTRICAL ENGINEER, age 27, married, 1923 graduate of University of Washington, hydroelectric experience; nineteen months General Electric Test. Desires to locate on Pacific Coast, position leading to executive responsibility with power company, industrial concern, or large distributor of electrical equipment. Available on short notice. C-742.

EXECUTIVE, age 43, married, thoroughly competent to take charge of office, plant or factory. Many years actual experience in organization, personnel management, valuation and appraisal, installations and supervision, office management, correspondent and special confidential investigations. Available at once. Location, New York or New Jersey. C-521.

EXECUTIVE ENGINEER, age 26, desires to change his position. Has had four years' experience as assistant superintendent and superintendent for various manufacturers making electrical, mechanical, and electro-mechanical devices. Work consisted of time studies, production control, cost analysis, cost forecasts, general factory supervision, etc. Graduate electrical engineer. B-5435.

ELECTRICAL ENGINEER with wide experience in developing intricate electro mechanical and structural problems. College graduate 1910, M. E. and E. E. degrees. Fifteen years' experience here and abroad. Age 40. Location preferred, New York City. A-165.

ELECTRICAL ENGINEER, university graduate, age 28, married, one year testing course, four years experience in construction and design of railway substations, outdoor stations and large hydro and steam power plants. Efficient worker. Desires position as assistant engineer or designer or resident engineer. Available on three weeks' notice. C-792.

ELECTRICAL ENGINEER OR SUPERINTENDENT, age 34, married, eleven years' experience power plant construction, operation and maintenance of same, on steam and hydro, including electric railway, substations, power distribution, transmission. Broad experience on industrial electrifications. Can make estimates and lay-out work. Desires connection with power or engineering company. Available February 15th. C-761.

TECHNICAL GRADUATE, class 1911, age 36, married, desires position as manager of small electric light plant. Have operated my own plant until it was purchased by a large corporation. Bought this plant when it was on the verge of failure and unaided put it on a good paying basis in five years. C-738.

GRADUATE ELECTRICAL ENGINEER, three years' experience in laboratory, testing and designing of steam and gas-electric power plants, including commercial work in responsible position. Can speak and write Spanish, German, French, Russian, Norwegian. Willing to go abroad. Available on two weeks' notice. C-503.

TEACHER OF E. E., young man with extensive training and broad experience desires position. M. S. degree from Cornell University. Practical experience at Westinghouse and other places. Teacher in university for five years, in charge of department two years. Successful as manager. Well liked by students and associates. Good references. B-4968.

ASSISTANT ELECTRICAL ENGINEER, for consulting engineer, public utility or manufacturer. Technical graduate, single, 25, four years' electrical power plant and manufacturing experience before entering college, last two years assistant engineer large public utility in charge electrolysis mitigation, factory inspection electrical equipment, general testing, associated in general design and research. Two weeks' notice. Location immaterial. Salary $165.00. B-9045.

ELECTRICAL ENGINEER, age 39, married, sixteen years' experience supervision design, installation, maintenance, operation nearly all kinds electrical apparatus on over seven thousand miles of railroad, including lighting of all kinds, motor installations, overhead, underground distribution and transmission, submarine cables, building wiring, power plant electrical equipment, industrial high tension substations, meter surveys, industrial trucks. B-9772

YOUNG MAN GRADUATING IN JUNE from M. I. T. in electrical engineering wishes position. Has spent summers in public utility work, both construction and office. Has done graduate work in central stations and distribution at M. I. T. Prominent in undergraduate activities. Location, East. C-803.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED JANUARY 15, 1926

ALBER, GROVER F., Primary Meter Inspector, The Detroit Edison Co., 2000 Second Ave., Detroit, Mich.

*ALEXANDER, DONALD FORD, Electrical Design Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.

*ALIFANO, ANTONIE, Senior Engineering Student, Brooklyn Polytechnic Institute, 85 Livingston St., Brooklyn; res., Ridgewood, Queens, N. Y.

*APPLETON, WILLIAM EDGAR, Electrical Dept., Gary Heat, Light & Water Co., Gary, Ind.

ARNOLD, GUY WALKER, Electrical Engineer, Canadian Westinghouse Co., Ltd., Hamilton, Ont., Can.

ASHLINE, ROBERT, Asst. to Head Dept. Electrolysis Mitigation, City of Los Angeles, 207 S. Broadway, Los Angeles; for mail, Inglewood, Calif.

AVERY, ARTHUR BENJAMIN, Jr., Student & Assistant, University of Arkansas, University Station, Fayetteville, Ark.

*AYRES, EDMUND DALE, Engineer, Jackson & Moreland, 31 St. James Ave., Boston, Mass.

*AYRES, FRANK, Student, The Southern Sierras Power Co., Riverside; res., Highgrove, Calif.

BABCOCK, GERHARDT M., Electrician, Los Angeles Gas & Elec. Corp., Los Angeles, Calif.

*BAILEY, CORNELIUS OLIVER, Radiologist, 912-14 Medical Arts Bldg., Dallas, Texas.

*BAKER, ACKLAND JAMES, Lakeside, Ont., Can.

BARSDORF, LEONARD WILLIAM, Switchboard & Meter Engineer, General Electric Co., Magnet House, Kingsway, London, Eng.

BATTISTA, LOUIS M., Service & Inspection Work, Socony Burner Corp., 40 Franklin St., So, Norwalk, Conn.

*BATY, LAURENCE EDWIN, Meter Tester, The Topeka Edison Co., 12th & Jackson Sts., Topeka, Kans.

*BAUMAN, HAROLD ADAMS, Assistant, Combustion Dept., Bethlehem Steel Co., Grey Mill Office, Bethlehem; res., So. Bethlehem, Pa.

BAUMGARDNER, CLAUDE GEROLD, Elec. Construction Foreman, Monongahela West Penn. Public Service Co., 504 Bethlehem Bldg., Fairmont, W. Va.

BEART, ERNEST ALFRED, Estimating Distribution Dept., Toronto Hydro-Electric System, Duncan St., Toronto, Ont., Can.

BEAUMONT, WILLIAM M., Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.; res., Summit, N. J.

BECKER, THEODORE, Inside Plant Div., Engg. Dept., Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

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PENNEY, WILLIAM MARCHANT, Jr., Ass't. Distribution Engineer, Union Electric Lt. & Pr. Co., 315 N. 12th St., St. Louis, Mo.
*PHILLIPS, STANLEY NEVILLE, Engineering Apprentice, Century Electric Co., 1806 Pine St., St. Louis, Mo.
PILKINGTON, JOHN HENRY, Technical Assistant, Brooklyn Edison Co., Pearl & Willoughby Sts., Brooklyn, N. Y.
*PREISMAN, ALBERT, Elec. Engg. Assistant, The New York Edison Co., 140th St. & Rider Ave., New York, N. Y.
RAE, O. O., Sales Engineer, Westinghouse Elec. & Mfg. Co., 426 Marietta St., Atlanta, Ga.
*RANSON, RICHARD R., Electrical Engineer, Experimental Dept., Cutler-Hammer Mfg. Co., Milwaukee, Wis.
RAPP, CARL P., Transmission Engineer, Bell Telephone Co. of Pennsylvania, 1230 Arch St., Philadelphia, Pa.
REARDON, MICHAEL F., Technical Clerk, Mountain States Tel. & Tel. Co., 800 14th St., Denver, Colo.
*REED, CALVIN FRANCIS, Student, International Standard Electric Corp., 25 Broad St., New York; res., Brooklyn, N. Y.
REED, F. FOSTER, Laboratory Assistant, Public Service Elec. & Gas Co., 21st St. & Clinton Ave., Irvington; res., Jersey City, N. J.
REED, GEORGE VICTOR, Chief Engineer, Provincial Hospital, Province of Saskatchewan; for mail, Weyburn, Sask., Can.
*REED, HARRY R., Jr., Special Apprentice, Norfolk & Western Railway Co., Roanoke, Va.
REED, WILLIAM H., Electrical Engineer, Tietjen & Lang Dry Dock Co., 17th St. & Park Ave., Hoboken, N. J; res., South Norwalk, Conn.
RICHARD, ERNEST CAMP, Asst. to Transmission Engineer, Florida Power & Light Co., Miami Beach, Fla.
RICHARDSON, MARSTON SAMUEL, Facilities Engineer, Wisconsin Telephone Co., 418 Broadway, Milwaukee, Wis.
RICHARDSON, RICHARD PAUL, Asst. Engineer, Electricity Dept., Sydney Municipal Council, Sydney, Austrailia.
RIHANEK, LADISLAV V., Electrical Designer, T. E. Murray, Inc., 55 Duane St., New York; res., Brooklyn, N. Y.
RIPLEY, NELSON ALDEN, Head of Material Dept., Phoenix Utility Co., Cienfuegos, Cuba.
ROBERTS, GEORGE ARTHUR, Telephone Equipment Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.
*ROBERTSON, GEORGE BAKER MAHN, Supervisor of Testing, Meter Laboratory, Philadelphia Electric Co., 2301 Market St., Philadelphia, Pa.
ROBSON, JOHN GREENFIELD, Operator, British Columbia Electric Railway Co., Vancouver, B. C.
ROESER, JOSEPH PETER, Inspector, Brooklyn Edison Co., Inc., Pearl & Willoughby Sts., Brooklyn, N. Y.
ROHDE, CHARLES F., Appraisal Engineer, Murrie & Co., 45 E. 17th St., New York; res., Brooklyn, N. Y.
ROLLOW, JAMES GRADY, Electrical Engineer, Los Angeles Gas & Electric Corp., 810 South Flower St., Los Angeles, Calif.
ROLNICK, Harry, Electrician, International Motor Co., 216 Seaman St., New Brunswick, N. J.
*ROSENBURG, EVERETT REYNOLDS, Student, Cornell University, 306 Stewart Ave., Ithaca, N. Y.
ROSS, DONALD, Member, Technical Staff, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.
*ROTH, JESSE E., Multiplex Plant Attendant, Western Union Telegraph Co., 7th & Walnut Sts., Kansas City, Mo.
*ROWLAND, DAVIDGE HARRISON, Engineer, Locke Insulator Corp., S. Charles & Cromwell Sts., Baltimore, Md.
*RUMSEY, PAUL TRUMAN, Instructor, Dynamo Laboratory Dept., Mass. Institute of Technology, Cambridge, Mass.
*SAMS, JAMES HAGOOD, Jr., Student, Cornell University, 324 College Ave., Ithaca, N. Y.
SAPPER, ROBERT T., Asst. Purchasing Agent, Century Electric Co., 1806 Pine St., St. Louis, Mo.
*SCHACHT, DELBERT HERMANN, Sales Engineer, Century Electric Co., 628 Granite Bldg., Rochester, N. Y.
SCHARDT, FREDERICK O., Foreman, Electrical Construction, Public Service Production Co., Kearny; res., Edgewater, N. J.
*SCHLECHTER, ARTHUR HERMAN, Estimator, New York & Queens Electric Light & Power Co., Central Service Sta., Flushing; for mail, Corona, N. Y.
*SCHMIDT, EUGENE, Tester, New York & Queens Electric Light & Power Co., Flushing; res., Brooklyn, N. Y.
SCHMITTER, RAY M., Inspection Maintenance Engineer, Western Electric Co., Inc., Hawthorne Sta., Chicago, Ill.; for mail, Mercedes, Texas.
*SCHROEDER, JOHN HENRY, Specification Engineer, Commonwealth Edison Co., 635 Edison Bldg., Chicago, Ill.
*SHEA, DENNIS C., Asst. to Electrical Engineer, Standard Oil Co., Bayway Refinery, Elizabeth, N. J.
SHELLEY, HARRY SANDBERG, Engr., Distribution Dept., Consolidated Gas & Electric Co., Monument & Constitution Sts., Baltimore, Md.
SIMON, RAPHAEL B., Telephone Systems Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.
*SIPKIN, GEORGE, Estimator, Interborough Rapid Transit Co., 600 W. 59th St., New York; res., Brooklyn, N. Y.
SISKIND, CHARLES S., Instructor, Milwaukee Vocational School, 6th & Prairie Sts., Milwaukee, Wis.
SKENE, ANDREW ALLISON, Engineer, Union Switch & Signal Co., Swissvale, Pa.
SKINNER, WILLIAM A., Electrical Foreman, Pennsylvania Power & Light Co., 117 E. Broad St., Hazleton, Pa.
SMITH, ARTHUR WILLIAM, Valuation Engineer, Murrie & Co., 45 E. 17th St., New York, N. Y.; res., Jersey City, N. J.
SMITH, ERMY R., Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.; res., Maplewood, N. J.
SMITH, HOWARD MARSHALL, Vice-President, S. Edw. Eaton & Co., 591 Hudson St., New York, N. Y.

*SONNEMANN, WILLIAM KNOX, Electrical Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.

SONNENFELD, HUGO, Chief Engineer & General Superintendent, Cable Manufacturing Co., Ltd., Bratislava, Czechoslovakia.

*STANKA, ERHARDT W., Electrical Designer, H. L. Doherty & Co., 60 Wall St., New York, N. Y.; res., Belleville, N. J.

STANLEY, JACK SQUIRE, Line Foreman, Los Angeles Railway Corp., 717 E. 16th St., Los Angeles, Calif.

STERNBERG, THEODORE AUGUST, Electrical Draftsman, New York Rapid Transit Co., 85 Clinton St., Brooklyn, N. Y.; res., North Bergen, N. J.

STROESSLER, HANS M., Draftsman, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

*STRONG, EVERETT MILTON, Instructor, Elec. Engg. Dept., Cornell University, Ithaca, N. Y.

STUMPF, MALCOLM WENDLING, Student Engineer, New Orleans Public Service, Inc., 201 Baronne St., New Orleans, La.

SUMMERS, CLIFFORD JOHN, Armature Winder, U. S. S. New Mexico, c/o Postmaster, San Francisco, Calif.

SUMMERS, HARRY ANDERSON, Engg. Dept., Bell Telephone Laboratories, Inc., 463 West St., New York; res., Brooklyn, N. Y.

SUTHERLAND, GEORGE ELMER, Electrician, Gibbs & Hill, Mullins; for mail, Princeton, W. Va.

SWORDS, EVERETT LAVON, Foreman of Operation, California-Portland Cement Co., Colton; res., San Bernardino, Calif.

*TANCK, HENRY, Asst. Engineer, Motor Engg. Dept., General Electric Co., River Works, West Lynn; res., Boston, Mass.

TAYLOR, ALFRED LINDSAY, Engineering Assistant, New York Telephone Co., 158 State St., Albany, N. Y.

TAYLOR, JAMES REUBEN, Salesman, Westinghouse Elec. & Mfg. Co., 1224 Miners Bank Bldg., Wilkes-Barre, Pa.

*TAYLOR, WILLIAM PRESTON, Electrical Testman, Cons. Gas Electric Lt. & Pr. Co., Baltimore, Md.

*TEALL, HARLEY ALBERT, Student, Kansas State Agricultural College, Manhattan, Kansas.

THERRIEN, RUSSELL WILLIAM, Elec. Engg. Dept., Commonwealth Power Corp., Jackson, Mich.

THIELEMANN, GEORGE J., Station Electrician, Public Service Co. of No. Illinois, Blue Island, Ill.

*THOMSON, JOHN MILTON, Transformer Engg. Dept., Canadian Crocker-Wheeler Co., Katharine St., St. Catharines, Ont., Can.

TOWNSEND, RICHARD LEE, Engineer's Assistant, Chesapeake & Potomac Telephone Co., 725 13th St., N. W., Washington, D. C.

*TRAVERS, FRED HARTT, Student Engineer, New England Tel. & Tel. Co., 50 Oliver St., Boston; res., Everett, Mass.

TREPTOW, FREDERICK WILLIAM, Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.; res., Weehawken, N. J.

UPHAM, EDGAR HARVEY, Supt., French Cable Co., Orleans, Mass.

VAN DENBURG, EARL D., Engineer, The Montana Power Co., Great Falls, Mont.

VASSALLO, ANTHONY, Electrical Expert, Service Shop, General Electric Co., 627 Greenwich St., New York; res., Brooklyn, N. Y.

VROOM, EDWARD, Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York; res., Ossining, N. Y.

*WAITS, CHARLES EDWARD, Student Engineer, Utica Gas & Electric Co., 222 Genesee St., Utica, N. Y.

*WALL, CHARLES LAYTON, Jr., Student Engineer, General Electric Co., West Lynn; res., Lynn, Mass.

WALTER, GEORGE D., Electrician, Biglerville, Pa.

WATSON, DONALD R., Designer, Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

WEAVER, EARLE F., Division Supt., Pennsylvania Power & Light Co., Mt. Carmel, Pa.

WERNER, HAROLD DOUGLAS, Engineer, Foundry Dept., General Electric Co., Erie, Pa.

WETHERELL, DONALD HENRY, Member, Technical Staff, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

WILLIAMS, HARRY KASTE, General Foreman, General Underground Construction, Hartford Electric Light Co., 266 Pearl St., Hartford, Conn.

WILLIAMS, THOMAS, Dist. Manager, East Penn Electric Co., Minersville, Pa.

WILSON, MYRON SHEDWOOD, Asst. Engineer, Standardizing Laboratory, General Electric Co., West Lynn, Mass.

WINSLOW, JOHN CLIFFORD, Electrical Engineer, Westinghouse Elec. & Mfg. Co., East Springfield, Mass.

WITBECK, ALLEN LEE, Special Apprentice, Chicago, Milwaukee & St. Paul Railway Co., Chicago, Ill.; for mail, Pullman, Wash.

WOLF, HERMAN B., Maintenance Foreman, Southern Power Co., Salisbury, N. C.

WOLFE, T. M., Salesman, Westinghouse Elec. & Mfg. Co., 1224 Miners Bank Bldg., Wilkes-Barre, Pa.

*WOODS, STEPHEN RICHARD, Student Employ, Westinghouse Elec. & Mfg. Co., Murfreesboro, Tenn.

WRIGHT, ROLAND M., Act. General Foreman of Equipment, Cincinnati Street Railway Co., Cincinnati, Ohio.

WYNKOOP, FRANCIS BRUYN, Charge of Elec. Lab. & Meter Dept., Interborough Rapid Transit Co., 600 W. 59th St., New York, N. Y.

Total 352.

*Formerly enrolled Students

ASSOCIATES REELECTED JANUARY 15, 1926

DRAKE, WILLIAM A., Member, Technical Staff, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

JOHO, E. C., Telephone Equipment Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

MacDONALD, DANIEL F., 171 E. 94th St., New York, N. Y.

SWAN, WALTER DOUGLAS, Asst. Foreman, Elec. Laboratory, Interborough Rapid Transit Co., 600 W. 59th St., New York, N. Y.

THOMPSON, STEPHEN WILKINS, Vocational Instructor, Dayton Co-operative Industrial High School, Stivers High School Bldg., Dayton, Ohio.

ASSOCIATES REINSTATED JANUARY 15, 1926

GREGSON, MONTRUVILA EDW., Asst. Superintendent, Bronx District, New York Edison Co., 140th St. & Rider Ave., New York, N. Y.

MEMBERS ELECTED JANUARY 15, 1926

BARKER, JOSEPH WARREN, Assoc. Professor of Elec. Engg., Mass. Institute of Technology, Cambridge, Mass.

BOMAN, CARL EMANUEL, Supervising Equipment Design Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

CLARKSON, ALBERT J., General Inspector, Elec. Div., New York Central Railroad Co., Grand Central Terminal, New York, N. Y.

COTA, ALEJANDRO R., Assoc. Editor, Business Publishers International Corp., 1403 Pennsylvania Bldg., New York; res., Queens Village, N. Y.

DIAZ, ENRIQUE, Controller Engineer, The British Thomson-Houston Co., Ltd., Rugby, Eng.

DODGE, WILLIAM LAMB, Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

FILER, WILLIAM L., Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

HORR, RAY LECKLEY, Supervisor of Methods & Results, Mountain States Tel. & Tel. Co., 800 14th St., Denver, Colo.

IRISH, JOSEPH, Member of Technical Staff, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

KELLY, MERVIN, Research Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

*KELTON, EDWIN COIT, Major, Corps of Engineers, U. S. Army, Washington, D. C.; res., Bethesda, Md.

KEMP, CHARLES GEORGE RIDGELY, Electrical Engineer, 16 S. 5th St., Reading; res., Wyomissing, Pa.

LATHROP, GEORGE MARTIN, Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.; res., East Orange, N. J.

MATTHIES, WILLIAM H., Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

MORTIMER, LOUIS ANDREW, Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

MURPHY, PAUL BUCKNER, Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York; res., Nyack, N. Y.

OBERNDORF, EDWIN S., Asst. Electrical Engineer, The J. G. White Engineering Corp., 43 Exchange Place, New York, N. Y.

NOBLE, ROY EDWIN, Member, Technical Staff, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

SHOPE, HARRY STEPHENSON, Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

SMITH, GORDON K., Equipment Development Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

TURNER, CLARENCE PORTER, Administrative Assistant, Marine Engg. Dept., General Electric Co., 1 River Road, Schenectady, N. Y.

VOORHIES, MICHEL B., Asst. Professor, Elec. Engg. Dept., Louisiana State University, Baton Rouge, La.

WISHART, RONALD S., Printer & Automatics Engineer, Postal Telegraph-Cable Co., 253 Broadway, New York; res., Rockville Center, N. Y.

FELLOW ELECTED JANUARY 15, 1926

CHATELAIN, MICHAEL A., Professor, Polytechnic Institute of Leningrad; Vice-President Central Electrotechnical Council, Prosp. of 25 October 6, Apt. 7, Leningrad, Russia.

TRANSFERRED TO GRADE OF FELLOW JANUARY 15, 1926

COPLEY, ALMON W., Manager, Engineering Division, Westinghouse Electric & Mfg. Co., San Francisco, Calif.

HIBBARD, TRUMAN, Secretary and Chief Engineer, Electric Machinery Mfg. Co., Minneapolis, Minn.

LEEDS, MORRIS E., President, Leeds & Northrup Co., Philadelphia, Pa.

WENNER, FRANK, Physicist, Bureau of Standards, Washington, D. C.

TRANSFERRED TO GRADE OF MEMBER JANUARY 15, 1926

EUSTIS, TRUMAN W., Superintendent, Canadian National Carbon Co., Ltd., Toronto, Ont.
FREEMAN, HADLEY F., Patent Lawyer, Cleveland, Ohio.
GILT, CARL M., Assistant Inside Plant Engineer, Brooklyn Edison Co., Brooklyn, N. Y.
GREEN, CHARLES W., Telephone Engineer, Bell Telephone Laboratories, Inc., New York, N. Y.
HOFFMAN, WILLIAM L., Assistant Engineer, Puget Sound Power & Light Co., Seattle, Wash.
JENNINGS, PHILIP D., Assistant Engineer, Puget Sound Power & Light Co., Seattle, Wash.
LAMB, FRANK B., Consulting Engineer, Member of Firm, West Virginia Engineering Co., Charleston, W. Va.
LOCKWOOD, ALVAH M., Field Superintendent, Phoenix Utility Co. of Cuba, Cienfuegos, Cuba.
LOWENBERG, MAURICE J., Electrical Engineer, Stone & Webster, Inc., Boston, Mass.
LOWRY, HITER H., Telephone Engineer, Bell Telephone Laboratories, Inc., New York.
MACIAS, CARLOS, Chief Engineer, Electromotor, S. A., Mexico D. F., Mexico.
MUSSER, HARRY P. President, West Virginia Engineering Co., Charleston, W. Va.
NETTLETON, LEROY A., Engineering Assistant, Brooklyn Edison Co., Brooklyn, N. Y.
REINMANN, F. L., Supt. Electric Department, Northern Indiana Gas & Electric Co., Hammond, Ind.
RHOADES, WALTER K., Professor of Electrical Engineering, Bucknell University, Lewisburg, Pa.
SHEDD, HORACE E., Superintendent, Appalachian Power Co., Bluefield, W. Va.
STAHL, CHARLES J., Manager, Illuminating Engineering Bureau, Westinghouse Elec. & Mfg. Co., South Bend, Ind.
VALK, EUGENE E., Engineer, Los Angeles Office, General Electric Co., Los Angeles, Calif.
WALKER, EWART B., Electrical Engineer, Canadian National Railways, Toronto, Ont.
WHITE, EDWARD J., Secretary, Treasurer, Engineer, Harris Wright Co., Inc., Newark, N. J.
WILLIAMS, LEROY C., District Manager, Pacific Electric Mfg. Co., Los Angeles, Calif.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meetings held January 11 and 25, 1926, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the National Secretary.

To Grade of Fellow

DIXON, AMOS F., Systems Development Engineer, Bell Telephone Laboratories, New York, N. Y.
McIVER, GEORGE W., Jr., Asst. Manager, Electrical Dept., Toledo Edison Co., Toledo, Ohio.
THOMS, ALEXANDER P., Asst. Supt., Street Department, Commonwealth Edison Co., Chicago, Ill.
WILLIAMS, SAMUEL B., Telephone Engineer, Bell Telephone Laboratories, New York, N. Y.

To Grade of Member

ADKERSON, BRANCH O., Inside Plant Engineer, American Tel. & Tel. Co., New York, N. Y.
AMBUHL, FRANK F., Asst. Chief Engineer, Toronto Hydro-Electric System, Toronto, Ont.
ARCEO, ANTONIO, Supt. of Distribution, Mexican Light & Power Co., Ltd., Mexico City, Mex.
BELL, JOHN H., Telegraph Engineer, Bell Telephone Laboratories, New York, N. Y.
BOSTATER, HERBERT L., Telephone Engineer, Bell Telephone Laboratories, New York, N. Y.
DAVIS, URIAH, Load Dispatcher, Commonwealth Edison Co., Chicago, Ill.
EASTHAM, MELVILLE, President and Engineer, General Radio Co., Cambridge, Mass.
ENGLE, MELVIN D., Engineer, Station Engineering Dept., Edison Electric Illuminating Co. of Boston, Boston, Mass.
EVANS, ROBERT D., General Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.
FRIEND, HENRY M., Cable Engineer, Hugh L. Cooper & Co., New York, N. Y.
GARY, LAURENCE A., Engineer, Transmission Dept., Pacific Tel. & Tel. Co., San Francisco, Calif.
HASTINGS, MILTON B., Vice-President, Powerlite Devices, Ltd., Toronto, Ont.
INNES, FRANK R., Asst. Editor, *Electrical World*, New York, N. Y.
KERSEY, GLEN B., Field Engineer, Commonwealth Edison Co., Chicago, Ill.
McDOWELL, H. E., Electrical and Mechanical Engineer, Texas Power & Light Co., Dallas, Tex.
NASH, JOHN F., Electrical Engineer and Division Manager, Appalachian Power Co., Bluefield, W. Va.
RADER, RAY, Assistant Engineer, Puget Sound Power & Light Co., Seattle, Wash.
ROBERTS, SPENCER, Engineer, Day & Zimmerman, Philadelphia, Pa.
SCOFIELD, EDWARD H., Engineer of Power, Twin City Rapid Transit Co., Minneapolis, Minn.
SMITH, GEORGE S., Instructor of Electrical Engineering, University of Washington, Seattle, Wash.
VANHALANGER, L. J., Sales Engineer, Westinghouse Electric & Mfg. Co., Chicago, Ill.
WAY, HOWARD E., Special Agent, Electrical Equipment Div., Bureau of Foreign and Domestic Commerce, Washington, D. C.
WREAKS, HUGH T., Manager, Detroit Office, Boston Insulated Wire & Cable Co., Detroit, Mich.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before February 28, 1926.

Aaroe, E., Electric Bond & Share Co., New York, N. Y.
Alger, C. S., Puget Sound Power & Light Co., Seattle, Wash.
Allschwager, O. A., Northern States Power Co., Minneapolis, Minn.
Altamirano, S. E., General Electric, S. A., Mexico D. F., Mex.
(Applicant for re-election).
Anderson, D. P., Western Electric Co., Chicago, Ill.
Anderson, W. B., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Apps, W. G., School of Engg. of Milwaukee, Milwaukee, Wis.
Baker, H. O., Western Electric Co., Inc., New York, N. Y.
Barrow, L. G., Brooklyn Edison Co., Brooklyn, N. Y.
Basurto, R., Control Electrotecnico de Mexico, Secretaria de Industria y Comercio, Mexico, D. F., Mex.
Bauer, C. A., Commonwealth Edison Co., Chicago, Ill.
Bauerschmidt, G. J., Commonwealth Edison Co., Chicago, Ill.
Baum, S. H., Chas. Freshman Co., New York, N. Y.
Baxter, N. M., (Member), The Ohio Public Service Co., Sandusky, Ohio
(Applicant for re-election.)
Berk, H. H., Puget Sound Power & Light Co., Seattle, Wash.
Biosca, L. F., Federal Radio Corp., Buffalo, N. Y.
Black, W. L., Bell Telephone Laboratories, Inc., New York, N. Y.
Blanding, W. P. T., Bureau of Pr. & Lt. of Los Angeles, Los Angeles, Calif.
Bollinger, N. H., Florida Pr. & Lt. Co., Miami, Fla.
Boyce, E. O., Philadelphia Electric Co., Philadelphia, Pa.
Boyce, W. H., Delta Star Electric Co., Chicago, Ill.
Boyer, Q. O., Commonwealth Edison Co., Chicago, Ill.
Bradfield, C. W., Duquesne Light Co., Pittsburgh, Pa.
Braun, A. W., William Braun & Co., New York, N. Y.
Bronski, C. R., Commonwealth Edison Co., Chicago, Ill.
Brown, G. R., Western Electric Co., Chicago, Ill.
Brugger, K. A., Public Utility Co., Chicago, Ill.
Budden, A. N., General Electric, S. A., Mexico D. F., Mex.
Buell, R. C., General Electric Co., Schenectady, N. Y.
Buhler, A. A., New York Telephone Co., New York, N. Y.
Bunce, L. I., The Belamose Corp., Rocky Hill, Conn.
Button, F. E., Hudson View Garden, W. 180th St., New York, N. Y.
Cadavero, A., New York Telephone Co., Brooklyn, N. Y.
Call, C. A., (Member), Ohio Insulator Co., Barberton, Ohio
Carney, J. S., Narragansett Electric Lighting Co., Providence, R. I.
Carr, A. V., Philadelphia Electric Co., Philadelphia, Pa.
Carrington, W. W., City of Norwich Gas & Elec. Dept., Norwich, Conn.
Charlton, O. E., Mass. Institute of Technology, Cambridge, Mass.
Chawner, W. R., Southern Sierras Power Co., Riverside, Calif.
Churchill, H., Public Service Production Co., Newark, N. J.
Clark, G. D., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Clark, J., Brooklyn Edison Co., Inc., Brooklyn, N. Y.
Cobb, P. G., Weston Electrical Instrument Corp., Newark, N. J.
Codding, L. W., Public Service Electric & Gas Co., Newark, N. J.
Colbert, H. H., Southern Utilities Co., Fort Meyers, Fla.
Comly, J. M., Brooklyn Edison Co., Brooklyn, N. Y.
Conner, J. S., Davis Clinic, Marion, Va.
Cook, A. C., Western Electric Co., Chicago, Ill.
Cook, L. D., Commonwealth Edison Co., Chicago, Ill.
Coop, E. R., General Electric Co., Lynn, Mass.
Coughlin, J. G., Brooklyn Edison Co., Brooklyn, N. Y.
Crawford, G. W., Garrison Vacuum Tube Div., G. E. Co., Harrison, N. J.
Crumley, H. L., Georgia Railway & Power Co., Atlanta, Ga.
Cummings, E. B., United Hudson Electric Corp., New Paltz, N. Y.
Datta, R. S., Bucyrus Co., S. Milwaukee, Wis.
Davis, F. R. J., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Davis, J. I., Commonwealth Edison Co., Chicago, Ill.

Doyle, E. B., Westinghouse Elec. & Mfg. Co., New York, N. Y.
DuBois, A. D., Electric Machinery Mfg. Co., Minneapolis, Minn.
(Applicant for re-election.)
Dunn, R. R., with James Walker, Chicago, Ill.
Eaton, H. L., Central Coal & Coke Co., Kansas City, Mo.
Eiser, A. L., Commonwealth Edison Co., Chicago, Ill.
Ellison, M. A., The Pacific Tel. & Tel. Co., San Francisco, Calif.
Elste, C., Standard Oil Co. of N. J., Bayway Refinery, Elizabeth, N. J.
Estrada, J. F., Havana Central Railroad Co., Havana, Cuba
Felty, W. D., Pittsburgh Transformer Co., Pittsburgh, Pa.
Field, A., Commonwealth Edison Co., Chicago, Ill.
FitzHugh, C. D., Commonwealth Edison Co., Chicago, Ill.
Forsyth, J., Jr., Electric Bond & Share Co., New York, N. Y.
Fosdick, E. R., Washington Water Power Co., Spokane, Wash.
Fredrichsen, A., Johns-Manville, Inc., Chicago, Ill.
Frisbie, C. G., Public Service Co. of No. Illinois, Chicago, Ill.
Gaezler, H., Electro-Dynamic Co., Bayonne, N. J.
Gahn, M. H., Adirondack Power & Light Corp., Schenectady, N. Y.
Galassi, D., (Member), Bell Telephone Laboratories, Inc., New York, N. Y.
Galloway, R. P., Northwestern Electric Co., Underwood, Wash.
Gary, McC. L., Radio Corp. of America, Mexico, D. F., Mex.
Gentry, F. M., The New York Edison Co., New York, N. Y.
Gibson, F. D., Commonwealth Edison Co., Chicago, Ill.
Gillis, J. A., New York Edison Co., New York, N. Y.
Goetschius, W. L., Commonwealth Edison Co., Chicago, Ill.
Gordon, G., Research & Consulting Engineer, Ridgewood, N. J.
Goring, F. C., Norwich Electric Co., Norwich, Conn.
Gould, A. I., Thos. E. Murray, Inc., New York, N. Y.
Gould, A. S., General Electric Co., Schenectady, N. Y.
Graham, W. F., Continental Gin Co., Birmingham, Ala.
Grant, J. B., General Electric Co., St. Louis, Mo.
Grenzebach, S. L., Toronto Hydro-Electric System, Toronto, Ont., Can.
Grimm, G. A., Commonwealth Edison Co., Chicago, Ill.
Grossman, A. J., Bell Telephone Laboratories, Inc., New York, N. Y.
Haifleigh, C. J., Commonwealth Edison Co., Chicago, Ill.
Hallead, H. A., Kohlenite Products Co., Inc., Chicago, Ill.
Hammond, O. W., General Electric Co., Erie, Pa.
Hansen, T., Pratt Low Preserving Co., Santa Clara, Calif.
Hartman, H. E., Kansas Gas & Electric Co., Wichita, Kans.
Hartshorn, K. L., Commonwealth Edison Co., Chicago, Ill.
Haynes, R. F., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Hazen, H. L., Mass. Institute of Technology, Cambridge A, Mass.
Hebling, A. G., United Electric Light & Power Co., New York, N. Y.
Hebrew, J. S., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Hecht, J. L., (Member), Public Service Co. of No. Ill., Chicago, Ill.
Henig, C. W., Detroit Edison Co., Detroit, Mich.
Heisler, F., Public Service Co. of No. Ill., Chicago, Ill.
Hinson, E. G., Commonwealth Edison Co., Chicago, Ill.
Hoadley, H. E., (Member), Ohio Public Service Co., Warren, Ohio
Holman, J. L., New Brunswick Telephone Co., Saint John, N. B., Can.
Horacek, J. A., (Member), Diamond Alkali Co., Painsville, Ohio
Hosticka, F. J., Western Electric Co., Chicago, Ill.
Huffman, H. F., University of Kansas, Lawrence, Kansas
Ingersoll, R. E., Westinghouse International Co., New York, N. Y.
Jarand, W. H., Northern Electric Co., Ltd., Montreal, Que., Can.
Jensen, P. J. S., Commonwealth Edison Co., Chicago, Ill.
Johnson, G. E., (Member), The Norwich Electric Co., Norwich, Conn.
Jones, R. H., The Milwaukee Elec. Rly. & Lt. Co., Milwaukee, Wis.
Jordan, W. C., Bell Telephone Laboratories, Inc., New York, N. Y.
Joseph W., Union Electric Light & Power Co., New York, N. Y.
Jost, E. R., Western Electric Co., Chicago, Ill.
Kaegi, E., American Brown Boveri Electric Corp., Camden, N. J.
Kannenberg, W. F., Bell Telephone Laboratories, Inc., New York, N. Y.
Kanzler, O. C., Commonwealth Edison Co., Chicago, Ill.
Katz, B. J., 187 Bank St., Burlington, Vt.
Keith, F. E., General Electric Co., Chicago, Ill.
Kidd, J. R., Bell Telephone Laboratories, Inc., New York, N. Y.
Kilstofte, I. N., Commonwealth Edison Co., Chicago, Ill.
Knost, J. H., Jr., (Member), Westinghouse Elec. & Mfg. Co., Los Angeles, Calif.
Knox, E. H., Electric Co. of New Jersey, Bridgeton, N. J.
Knowlton, W. D., Commonwealth Edison Co., Chicago, Ill.
Koschmeder, L. A., East Penn. Electric Co., Pottsville, Pa.
Kramer, J., Jr., Western Electric Co., Inc., Chicago, Ill.
Krejci, F. V., Commonwealth Edison Co., Chicago, Ill.
Kremer, J., 135 Central Park West, New York, N. Y.
Krueger, N. C., Commonwealth Edison Co., Chicago, Ill.
Kuhles, W. J., Commonwealth Edison Co., Chicago, Ill.
La Fever, L. H., 444 Cass St., Milwaukee, Wis.
Lambert, T. J., Brooklyn Edison Co., Brooklyn, N. Y.
Langley, E. J., Union Elec. Light & Power Co., St. Louis, Mo.
Langsam, H., 2215 N. 29th St., Philadelphia, Pa.
Largy, V. P., New York Dock Co., Brooklyn, N. Y.
Larson, C. A., Auto Specialties Co., Elkhart, Ind.
Laws, F. R., Edison Electric Ill. Co., Boston, Mass.
Leidenheimer, F. J., Baldor Electric Co., St. Louis, Mo.
Leon, C., Jr., Havana Central Railroad Co., Havana, Cuba
Leonard, R. N., New York Edison Co., New York, N. Y.
Lindblom, R. E., University of Washington, Seattle, Wash.
Long, F. A., Commonwealth Edison Co., Chicago, Ill.
Long, P. B., Union Switch & Signal Co., Swissvale, Pa.
Lorich, R. A., N. Y. & N. J. State Bridge & Tunnel Comm., New York, N. Y.
Loshbough, L., General Electric Co., Chicago, Ill.
Love, E. L., Western Electric Co., Inc., New York, N. Y.
Lund, A., Stone & Webster, Inc., Boston, Mass.
Lundgren, F. E., General Electric, S. A., Mexico D. F., Mex.
Maheu, J. J., Western Electric Co., Inc., Chicago, Ill.
Manspeaker, E. D., General Electric Co., Schenectady, N. Y.
Many, W. G., Radio Review, New York, N. Y.
Markers, H. W., Commonwealth Edison Co., Chicago, Ill.
Martin, E. F., General Electric Co., Bloomfield, N. J.
Masuno, T., Stone & Webster, Inc., Boston, Mass.
Mausshardt, M. R., Key System Transit Co., Oakland, Calif.
McClarren, A. E., Puget Sound Power & Light Co., Seattle, Wash.
McGowan, L. F., Rochester Gas & Electric Co., Rochester, N. Y.
McKinley, J. L., Public Service Co. of Colorado, Denver, Colo.
McLean, J., Commonwealth Edison Co., Chicago, Ill.
Mercereau, J. T., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Merrill, M. S., General Electric Co., Schenectady, N. Y.
Metz, J., Commonwealth Edison Co., Chicago, Ill.
Michael, J. J., Pacific Tel. & Tel. Co., Seattle, Wash.
Miller, F. H., with Frank A. Boedtcher, New York, N. Y.
Miller, J. H., Firestone Tire & Rubber Co., Johnstown, Pa.
Miller, R. F., Naomi Pines Electric Co., Inc., Pocono Pines, Pa.
Miller, R. F., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Miller, W. H., Canadian Westinghouse Elec. & Mfg. Co., Toronto, Ont., Can.
Misner, F. D., Commonwealth Power Corp., Jackson, Mich.
Mitchell, J. I., Public Service Co. of No. Illinois, Evanston, Ill.
Miyasaki, M., University of Wisconsin, Madison, Wis.
Mode, H. C., Westinghouse Elec. & Mfg. Co., Philadelphia, Pa.
Molina, F., J., Calle 59 No. 447, Merida, Yucatan, Mex.
(Applicant for re-election).
Monaco, J., with M. R. Greenblatt, Brooklyn, N. Y.
Mussfeldt, A., Public Service Co. of No. Ill., Chicago, Ill.
Muth, L. R., Junior Elec. Draftsman, City of Seattle, Seattle, Wash.
Myers, F. W. A., Philadelphia Electric Co., Philadelphia, Pa.
Nelson, N., Adirondack Power & Light Corp., Schenectady, N. Y.
Olds, C. D., Puget Sound Pr. & Lt. Co., Bellingham, Wash.
Ortlieb, O. P., Street Lighting Engr., City of Trenton, Trenton, N. J.
Otto, E. D., Royal Eastern Electrical Supply Co., New York, N. Y.
Over, H. A., Commonwealth Edison Co., Chicago, Ill.
Palmer, G. W., L. D. Smith Dock Co., Sturgeon Bay, Wis.
Patterson, E. B., "Public Ledger" & "Evening Ledger," Philadelphia, Pa.
Pennybacker, M., Raytheon Mfg. Co., Cambridge, Mass.
Perry, D. J., Bell Tel. Co. of Pa., Philadelphia, Pa.
Peterson, V. C., Western Electric Co., Cicero, Ill.
Pettet, C. C., Northern Electric Co., Ltd., Montreal, P. Q., Can.
Philleo, E. W., Victor X-Ray Corp., San Francisco, Calif.
Polley, L. P., Puget Sound Power & Light Co., Tacoma, Wash.
Price, A. V., Northern Electric Co., Toronto, Ont., Can.
Price, J. R., Western Electric Co., New York, N. Y
Pruddhomme, D. J., Oregon State College, Corvallis, Ore.
Putnam, R. C., Case School of Applied Science, Cleveland, Ohio
Rankin, H. C., The New York Edison Co., New York, N. Y.
Reilly, F. W., General Electric Co., Boston, Mass.

Reimel, S. R., B. D. Goodrich Co., Akron, Ohio
Rice, J. M., Pennsylvania State College, State College, Pa.
Richards, F. I., General Electric Co., Schenectady, N. Y.
Rieman, H. M., Central Hudson Gas & Electric Co., Poughkeepsie, N. Y.
Rodewig, L. F., General Electric Co., New York, N. Y.
Roger, W. H. G., c/o Fraser, Frew & Dryer, Ltd., Vancouver, B. C.
Rose, D. L., So. California Edison Co., Big Creek, Calif.
Ross, W., with James Martin, New York, N. Y.
Roughen, R. H., (Member), Duquesne Light Co., Pittsburgh, Pa.
Rowley, C., Commonwealth Edison Co., Chicago, Ill.
Ruppell, E. A., Kimball Elec. Construction Corp., New York, N. Y.
Sassen, C. H., Hudson Coal Co., Scranton, Pa.
Schaefer, P. E., Commonwealth Edison Co., Chicago, Ill.
Schnug, G., Pacent Electric Co., Inc., New York, N. Y.
Schroeder, H. W., Commonwealth Edison Co., Chicago, Ill.
Schultz, H. G., Commonwealth Edison Co., Chicago, Ill.
Schultz, S. W., Commonwealth Edison Co., Chicago, Ill.
Scott, C., Commonwealth Edison Co., Chicago, Ill.
Sederberg, N. W., Brooklyn Edison Co., Brooklyn, N. Y.
Seelye, A. F., Boise Payette Lumber Co., Barber, Idaho
Sharpsteen, J. K., Pacific Gas & Electric Co., San Francisco, Calif.
Shulze, G. F., Bell Telephone Laboratories, Inc., New York, N. Y.
Shuman, U. S., Philadelphia Suburban Gas & Electric Co., Newtown, Pa.
Sibley, W. C., Commonwealth Edison Co., Chicago, Ill.
Sisler, F. G., The Electric Controller & Mfg. Co., Cleveland, Ohio
Smith, H. W., Commonwealth Edison Co., Chicago, Ill.
Smith, J. L., Commonwealth Edison Co., Chicago, Ill.
Smith, O., Thomas E. Murray, Inc., New York, N. Y.
Smith, V. G., University of Toronto, Toronto, Ont., Can.
Smith, W. J., Commonwealth Edison Co., Chicago, Ill.
Spencer, R. M., (Member), Los Angeles Gas & Elec. Co., Los Angeles, Calif.
Stahl, C. P., General Electric Co., Schenectady, N. Y.
Starr, A. L., Clapp & LaMores, Los Angeles, Calif.
Steinberg, B. B., New York Edison Co., New York, N. Y.
Stock, R. J., Supervisor. Electrical Equipment, Cincinnati, Ohio
Story, T. H., Turner Construction Co., New York, N. Y.
Stover, M. M., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Stover, J. R., Metropolitan Edison Co., Reading, Pa.
Stowers, L. G., Southern Bell Tel. & Tel. Co., Atlanta, Ga.
Sudler, E. O., Bliss Electrical School, Washington, D. C.
Taggart, C. W., City of Norwich Gas & Elec. Dept., Norwich, Conn.
Taylor, F. F., Salt River Valley Water Users Assn., Roosevelt, Ariz.
Tarzian, S., Atwater Kent Mfg. Co., Philadelphia, Pa.
Thomas, C. H., Electrical Testing Laboratories, New York, N. Y.
Thomas, W. A., 3rd, (Member), Sonora Phonograph Co., Inc., New York, N. Y.
Thompson, A. C., American Tel. & Tel. Co., New York, N. Y.
Thompson, G. S., Colorado Fuel & Iron Co., Pueblo, Colo.
Thompson, H. E., Brooklyn Edison Co., Brooklyn, N. Y.
Thomson, T. B., U. S. E. M. Co., New York, N. Y.
Thorson, W. R., Commonwealth Power Corp., Jackson, Mich.
Thurston, H. A., Columbus Railway, Power & Light Co., Columbus, Ohio
Tietz, W. J., Western Electric Co., Inc., Chicago, Ill.
Tisdale, W. H., Connecticut Power Co., Middletown, Conn.
Torgan, N., Jr., Horni Signal Mfg. Corp., Newark, N. J.
Trimble, L., Commonwealth Edison Co., Chicago, Ill.
Trone, E. M., Western Electric Co., Inc., Chicago, Ill.
Tuckerman, L. P., De Forest Radio Co., Jersey City, N. J.
Van Etten, F. C., Delta Star Electric Co., Columbus, Ohio
Van Sickle, R. C., Westinghouse Elec. & Mfg. Co., Wilkinsburg, Pa.
Van Why, F. W., Passadena Star-News, Pasadena, Calif.
Walker, F. V., Bureau of Pr. & Lt. of Los Angeles, San Fernando, Calif.
Wallis, C. G., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Weber, H. P., Commonwealth Edison Co., Chicago, Ill.
West, G. H., Louisiana Electric Co., Inc., Lake Charles, La.
Westbrook, J. L., Compania Agricola y de Fuerza Electrica del Rio Conchos, S. A., C. Camargo, Chih., Mex.
Westerman, A. G., Commonwealth Edison Co., Chicago, Ill.
Westhoven, C. J., Commonwealth Edison Co., Chicago, Ill.
Whitaker, E. R., Union Electric Light & Power Co., Ashley Station, St. Louis, Mo.
Wick, R. J., Commonwealth Edison Co., Chicago, Ill.
Wilbur, D. E., Pennsylvania Pr. & Lt. Co., Allentown, Pa.
Wilcox, J. E., New York Telephone Co., New York, N. Y.
Williams, G. H., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Williams, N. B., Puget Sound Power & Light Co., Seattle, Wash.
Winograd, H., American Brown Boveri Electric Corp., Camden, N. J.
Wishard, W. W., Commonwealth Edison Co., Chicago, Ill.
Wollebak, T., Delta Star Electric Co., Chicago, Ill.
Wright, C. T., (Member), The Pennsylvania-Ohio Pr. & Lt. Co., Toronto, Ohio
Young, P. N., Brooklyn Edison Co., Brooklyn, N. Y.
Turner, H. E., General Electric Co., Schenectady, N. Y.
Zimmer, F. M., Ohio Power Co., Canton, Ohio
Total 242

Foreign

Akers, R. E., (Member), Carrick Wedderspoon, Ltd., Christchurch, N. Z.
Albiston, W. A., Christmas Island Phosphate Co., Christmas Island, Indian Ocean
Bhaman, R. C., Tata Iron & Steel Co., Ltd., Jamshedpur, India
Buchanan, T., The British Thomson-Houston Co., Ltd., Willesden, London, N. W., 10, Eng.
Downie, C. G., Metropolitan-Vickers Elec. Co., Ltd., Manchester, Eng.
Ferreira, A. C., The Sao Paulo Tramway Lt, & Pr. Co., Sao Paula, Brazil, S. A.
German, C., College of Engg., Univ. of Philippines, Manila, P. I.
Glover, G. C., Chile Exploration Co., Chuquicamata, Chile, S. A.
Jacobsen, C. J., Braden Copper Co., Rancagua, Chile, S. A.
Kirkpatrick, K. J., Metal Manufacturers Proprietary, Ltd., Port Kembla, N. S. W., Aus.
Kloss, M., (Fellow), Technische Hochschule, Charlottenburg, Germany
Longy, V., British Engine, Boiler & Electrieal Ins. Co., Barcelona, Spain
Milne, K. H., Adelaide Electric Supply Co., Ltd., Adelaide, South Australia
McCulloch, H., Hydroelectric Dept., Hobart, Tasmania
Monroe, G. W., Braden Copper Co., Rancagua, (Pangal), Chile, S. A.
Mountain, C. E., Burma Elec. Tramways & Lighting Co., Ltd., Mandalay, Burma, India
Nixon, J. H. R., Messrs. Brush Elec. Engg. Co., Ltd., Loughborough, Leicestershire, Eng.
Noguchi, K., Mitsubishi Research Laboratory, Komagome, Hongo, Tokyo, Japan
Patel, D. B., Brown, Boveri & Co., Baden, Switzerland
Sahgal, G. R., Engineering College, Poona, India
Scanlon, D. L., Chile Exploration Co., Chuquicamata, Chile, S. A.
Sharma, S. M., Messrs. India Elec. House, Delhi, India
Sleeman, H., (Member), Electric Tramway & Supply Co., Rangoon, Burma, India
Thomspon, A. L., (Fellow), La Carlota Sugar Central, La Carlota, Negros Occ., P. I.
Timoffeeff, W. A., Electrotechnical Inst. of Leningrad, Leningrad, Russia
Total 62

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Agnew, Norman F., Ohio State University
Akers, Chauncey Lee, Rose Poly. Inst.
Anderson, Aldrich B., Case School of Applied Science
Asfalt, Filip J., Univ. of Minn.
Bailey, Homer L., Worcester Poly. Inst.
Bailey, Stuart L., Univ. of Minnesota
Baines, Harold A., Worcester Poly. Inst.
Baker, Allan K., Univ. of Michigan
Barberie, Frederick M., Virginia Military Inst.
Barton, James P., Univ. of Minnesota
Bates, Allen W., Northeastern Univ.
Bauer, Rudolph W., Penn. State College
Beach, George, Univ. of Minnesota
Benedict, John C., Univ. of Michigan
Berger, Harold J., Univ. of Wisconsin
Berglund, Erick B., Univ. of Minn.
Berkner, Lloyd V., Univ. of Minn.
Bezek, Albert J., Univ. of Minnesota
Bickmore, William J., Ohio State Univ.
Bishop, W. E., Univ. of Maryland
Blanchard, J. Wayne, New York Univ.
Blankenbeker, Everett L., Kansas State College
Boger, Clair E., Ohio State Univ.
Boisseau, Alexander C., Washington & Lee Univ.
Bonner, Arthur L., Univ. of Minnesota
Boyce, Harold J., Univ. of Minn.
Bricker, Lowell E., Ohio State Univ.
Brightfelt, John C., Univ. of Minn.
Briscoe, Andy, Montana State College
Brooke, Edward F., Ohio State Univ.
Brooks, James W., Cornell Univ.
Brooks, Ralph R., Univ. of Wisconsin
Brown, Frederick A., Lewis Inst.
Brown, George E., Ohio State Univ.
Brown, George W., Ohio State Univ.
Brown, Percy S., Univ. of Southern California
Broyles, Harmon E., Virginia Poly. Inst.
Buccowich, Paul, Univ. of Minnesota
Burmeister, Charles H., Univ. of Minnesota
Campbell, James L., N. Car. State College
Carlson, C. Paul, Univ. of Michigan
Carson, Lester G., N. Car. State College
Carson, Sam A., Jr., Virginia Military Inst.
Case, Myron D., Stanford Univ.
Cerney, Jospeh A., Case School App. Science
Chute, Dudley H., Northeastern Univ.
Clancy, Walter J., Univ. of Pa.
Connolly, Ethan F., Univ. of Toronto
Cook, F. W., Ohio State Univ.
Cook, William P., Ohio State Univ.

Cooper, C. M., N. Car. State College
Cooper, George V., Univ. of Denver
Copper, Joseph B., Wash. & Lee Univ.
Cox, Lester D., Ohio State University
Cram, Charles C., Ore. Agri, College
Craugh, Paul T., N. Y. Univ.
Crawford, Kelsey, Univ. of Okla.
Croll, Raymond H., Ohio State Univ.
Cruse, J. W., Univ. of Arizona
Dannecker, Martin C., Purdue Univ.
Davis, Julius E., North Car. State College
Dearth, Sam C., Ohio State Univ.
Decino, Alfred, Univ. of Colo.
DeHaven, Thomas V., Univ. of Denver
Deist, John W., Univ. of Wisconsin
De Jean, Clare L., Penn. State College
Delong, Carl I., Ohio State Univ.
DeStefano, Anthony C., Polytechnic Institute of Brooklyn
Dexter, D. M., Univ. of Arizona
Divguid, John H., Virginia Military Inst.
Dolezal, Edward G., Case School of Applied Science
Dortort, Isadore, Univ. of Pa.
Douglas, A. J., Univ. of Toronto
Dreher, Carl E,, Rose Poly. Inst.
Dresser, Weyburn H., Univ. of Wisconsin
Due, Paul A., Ore. State College
Dunn, Charles, Jr., Univ. of Arizona
Dunn, W. Francis, Cornell Univ.
Eatman, Frank L., Jr., Univ. of Alabama
Eckstein, Moritz, N. Y. Univ.
Edgar, Merton W., Univ. of Denver
Edgar, Robert F., Univ. of Minn.
Edwards, Manley W., Cal. Inst. of Tech.
Ellis, Clarence W., Rose Poly. Inst.
Fagan, James W., N. Car. State College
Fahlstrom, Clifford I., Worcester Poly. Inst.
Fairchild, Marshal T., N. Car. State. College
Falls, Theodore F., Univ. of Pa.
Fatig, Raymond O., Ohio State Univ.
Ferris, W. Robert, Rose Polytechnic Inst.
Fischer, Edgar C., Newark Technical School
Fowler, Robert E., Cornell Univ.
Fraser, Willard B., McGill Univ.
Freston, Robert B., Lewis Inst.
Frink, Frederick W., Leland Stanford Univ.
Fulton, Walter J., Univ. of Pa.
Gartin, James W., Univ. of Idaho
Gerhan, Charles F., Case School of Applied Science
Gibson, Robert, Univ. of Minn.
Glover, Robert L., Univ. of Pa.
Goldman, Samuel, Lewis Inst.
Goldsmith, Lloyd T., Poly. Inst. of Brooklyn
Goodlin, Carl L., Ohio State Univ.
Graf, Glenn F., Ohio State Univ.
Graham, William M., Montana State College
Green, Francis N., University of Tennessee
Griffith, Lewis S., Virginia Military Inst.
Hamilton, Sam, Univ. of Alabama
Hammell, Kemper M., Ohio State Univ.
Haner, Norman W., University of Washington
Hansen, Elmer, Worcester Poly. Inst.
Hardy, Wilbur G., Ohio State U.
Hargreaves, William, Northeastern Univ.
Hargrove John W., Va. Poly. Inst.
Harris, Henry J., Va. Poly. Inst.
Harris, William A., Rose Poly. Inst.
Hawk, O. L., Lewis Inst.
Hayashi, Francis M., Stanford U.
Haydock, Jesse G., Jr., Univ. of Pa.
Hendershott, Leroy W., Ohio State University
Hicks, Ben C., McGill Univ.
Hitchcock, Jackson G., Jr., Univ. of Alabama
Hilbert, Walter F., Worcester Poly. Inst.
Hill, Carl C., N. Car. State College
Hobson, Leland S., Kansas State Agri. College
Hoody, J. Stanley, Ohio St. Univ.
Hopkins, Alva R., Ohio State U.
Hortberg, Reynold O., Univ. of Minn.
Howe, James S., Lewis Inst.
Huggins, Allen E., N. Car. State College
Hughes, Kenneth M., Ohio State Univ.
Hulstede, George E., Stanford Univ.
Humbert, Locke R., N. Car. State College
Humphrey, George D., N. Car. State College
Hurley, Henry C., N. Car. State College
Hutcheson, Richard M., Virginia Poly. Inst.
Hyde, H., Univ. of Toronto
Hyer, John, Kansas State Agri. College
Joehlin, Homer W., Ohio State Univ.
Jones, Robert F., Ohio State U.
Kadota, Koichi, Univ. of Toronto
Kane, Elias K., Univ. of Ill.
Kappanadze, Roman J., Case School of Applied Science
Karakiz, Socrates, Lewis Institute
Keller, G. V., Jr., N. Car. State College
Kemp, Russell E., Ohio State Univ.
King, Belton D., Clemson College
Kingston, George H., McGill Univ.
Kinnear, Arthur, Stanford Univ.
Kinsey, Alfred S., Cornell Univ.
Kleiner, Eugene M., Ore. Agri. College
Kloster, Walter W., University of N. Dak.
Knowles, Howard F., Northeastern Univ.
Kohler, Richard William, Washington State College
Krebs, Sylvester G., Case School Applied Science
Kres, Alfred J., Case School of Applied Science
Kromm, Charles F., Brooklyn Poly. Inst.
Lally, C. K., Univ. of Toronto
Lane, William C., Jr., N. Car. State College
Leahy, Edward F., Univ. of Pa.
Lee, Albert C., Univ. of Minn.
Lee, Paul R., Univ. of Minn.
Leedy, Walton O., Ohio State Univ.
Legge, Thomas A., Univ. of Toronto
Lehman, Charles D., Ohio State Univ.
Leider, Albert E., Univ. of Minn.
Lewis, Lloyd W., Univ. of Minn.
Ligh, Charles, New York Univ.
Lightfoot, Thomas C., Swarthmore College
Lowrance, Frederick H., Univ. of Minn.
Lussky, Lionel B., Denver Univ.
MacCannon, Bruce T., Univ. of Denver
Magne, Robert, Drexel Inst.
Marquette, Fabian W., Ohio St. U.
Marzulli, Angelo M., Purdue Univ.
Matsch, Leander W., Lewis Inst.
Mathews, William E., N. Car. State College
Mattes, William F., Jr., New York Univ.
Maxim, George, Case School of Applied Science
May, John Willard, Washington State College
Mayer, Philip H., Univ. of Pa.
McColl, F. Harold, Univ. of Toronto
McCulloh, Marvin W., N. Car. State College
McCullough, J. R., Univ. of Toronto
McDonnell, Lawrence, Univ. of Minn.
McGarrell, Edmund J., Worcester Poly. Inst.
McGuire, C. H., Univ. of Toronto
McPheeters, John W., Purdue Univ.
Mead, Rolan J., Northeastern Univ.
Mebs, Russell W., Ohio State Univ.
Mekeel, Nelson M., Ore. Agri. College
Mendelsohn, Harry, Univ. of Michigan
Merkle, Joseph D., Ohio State Univ.
Messex, Leland C., Univ. of Colo.
Michels, Walter C., Rensselaer Poly. Inst.
Miller, Earl R., Okla. A. & M. College
Miller, Edward F., State Univ. of Iowa
Miller, John W., Ohio State University
Miller, Sennet W., Case School Applied of Science
Milligan, Fred C., Ohio State Univ.
Mills, Lester F., N. Y. U.
Minici, Joe, Jr., Univ. of Colo.
Moccabee, Frederick M., Ohio State Univ.
Mong, Frederick M., Ohio St. U.
Montgomery, C. G., N. Car. State College
Moore, Gordon B., Univ. of Minn.
Moore, William H., McGill Univ.
Morris, Edmund T., Jr., Virginia Military Inst.
Morris, John C., Cornell, Univ.
Morrow, Thomas A., N. Car. State College
Muir, Walter, Cornell U.
Murray, John M., Northeastern Univ.
Mustoe, Anthony Q., Virginia Poly. Inst.
Neisser, Wilson R., Univ. of Pa.
Nelson, Clarence E., Univ. of Minn.
Nelson, John M., Univ. of Iowa
Nemela, Hugo W., Univ. of Wisconsin
Nielsen, Andres H., Univ. of Minnesota
Nolan, George C., Univ. of Minn.
Nuhfer, William L., W. Va. Univ.
Oberg, Rudolph O., Northeastern University
Oliver, Franklin S., Va. Poly. Inst.
Paisley, S. Roy, Univ. of Toronto
Palmer, Carl C., Purdue Univ.
Parr, Merl W., Univ. of Wisconsin
Patrick, Horace M., Penn. State College
Pering, Alfred V., Stanford Univ.
Peters, C. Max, Univ. of Minnesota
Peterson, Carl L., Case School of Applied Science
Pettibone, Gilbert W., Univ. of Southern Calif.
Phillips, Carey A., N. Car. State College
Pickford, Stanley H., Worcester Poly. Inst.
Pilger, Clarence L., Univ. of Minnesota
Plank, Lewin H., Univ. of Denver
Plott, Hubert K., N. Car. State College
Pollock, C. A., Univ. of Toronto
Porter, Charles S., Northeastern Univ.
Prasar, Hans R., Univ. of Wisconsin
Prentke, Edwin M., Case School of Applied Science
Prescott, Harold R., Univ. of Kansas
Pritchett, Edward H., Univ. of Alabama
Quinean, H. D., Univ. of Toronto
Quinlan, Joseph W., U. of Notre Dame
Raichilson, Robert, Univ. of Michigan
Rauscher, Paul F., Univ. of Minn.
Rawlins, Herbert L., Ohio State Univ.
Rawls, James A., Va. Polytechnic Inst.
Recer, Beo W., Okla. Agri. & M. College
Reed, Donald P., Worcester Poly. Inst.
Rembusch, Joseph E., Purdue Univ.
Rew, Clair W., Case School of Applied Science
Richart, Ralph R., Univ. of Ill.
Rindlaub, Willard W., Univ. of Pa.
Rinehart, Vene E., Oregon Agri. College
Riordan, Forrest H., Jr., Univ. of Pa.
Ritland, Hubert O., Stanford Univ.
Roberts, Walter F., Ohio State U.
Roberts, William F., N. Car. State College
Robinson, Lawrence T., Univ. of Minn.
Robinson, Richard B., Univ. of Minnesota
Rockfield, Martin L., N. Car. State College
Rohn Richard L., University of Denver
Rolston, David R., Va. Polytechnic Inst.
Rooney, Lewis K., Case School of Applied Science
Rumble, George, Univ. of Toronto
Rutherford, James F., McGill University
Sabbagh, Elias M., Ohio State U.
Sano, Joseph Y., Stanford Univ.
Scarafino, Anthony J., Poly. Inst. of Brooklyn
Schmal, Charles L., Lewis Inst.
Scholz, Edmund H., Univ. of Minn.
Schramm, John W., W. Va. Univ.
Schultz, Albert W., Univ. of Minnesota
Schulze, Leroy E., Univ. of Minn.
Sciotti, Fred, Brown University
Sckerl, Alfred, S. Dakota State College
Shiland, J. E., Case School of Applied Science
Sinclair, Shull A., Univ. of Arizona
Singer, Ferdinand Leon, New York Univ.
Singer, Willard E., Ohio State Univ.
Skilling, Hugh H., Stanford Univ.
Smathers, James L., N. Car. State College
Smith, James A., N. Car. State College
Snively, L. Clifton, Univ. of Colo.
Sparrow, Chester D., Univ. of Missouri
Stallard, Guy H., Rose Poly. Inst.
Stone, Walter, Purdue Univ.
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Tanner, Stephen C., Univ. of Colo.
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Teed, Currie N., Univ. of Idaho
Test, Laurence J., Swarthmore College
Thomas, Almon D. Thomas, Univ. of Colorado
Thompson, Samuel, Montana State College
Thomson, William L., Cornell Univ.
Townsend, H. J., Northeastern University
Tucker, Everett L., Oregon Inst. of Technology
Van Cleve, Charles F., Ohio State Univ.
Vaughn, Gerald O., Stanford U.
Verman, Lal C., Univ. of Michigan

Vest, William L., Jr., N. Car. State College
Vietzen, Elmer R., Lewis Inst.
Vieweger, Arthur, Univ. of Pa.
Volkenant, Gordon W., Univ. of Minn.
Wahrman, Harry, Va. Poly. Inst.
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Ward, Stanley A., Univ. of Minn.
Wasson, Arthur, Kansas State Agri. College
Watts, Plato Hilton, N. Car. State College
Webb, G. Kenneth, Northeastern University
Webb, Grady W., Va. Poly. Inst.
Weeks, L. H., Univ. of Minn.
Wehlitz, Hubert F., Univ. of Minn.
Weis, Jacob F., Ohio State Univ.
Westerberg, Oliver D., Lewis Inst.
White, James W., N. Y. U.
Whitely, Howard O., Univ. of Minn.
Wiggins, Leonard A., Ohio State U.
Wike, Reginald E., Ohio State Univ.
Williams, William W., Jr., Ohio State U.
Willson, Harry Leon, Rose Poly. Inst.
Wilson, Edwin W., N. Car. State College
Wirtel, William E., Univ. of Missouri
Wood, John Samuel, N. Car. State College
Woodring, William R., Kansas State Agri. College
Word, George L., Jr., Georgia School of Technology
Worth, Donald G., Univ. of Southern Cal.
Wrasman, John J., Ohio State Univ.
Yarling, Frank C., Purdue Univ.
Yeager, Robert, Jr., Virginia Military Inst.
Yusas, Mathew, Lewis Inst.
Zulandt, George K., Ohio State Univ.

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See the January issue for the latest published list. The Institute now has 50 Sections and 84 Branches.

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies

Switchboards.—Bulletin 111, 4 pp. Describes "Ideal" switchboards and synchronous motor starting panels. The Ideal Electric & Mfg. Company, Mansfield, O.

Blowers.—Bulletin 1608, 16 pp. Describes "ABC" pressure blowers and exhausters. American Blower Co., Detroit, Mich.

Steam Turbine Generators.—Bulletin GEA-54, 44 pp. Principally a photographic presentation of the Curtis turbine as installed in notable power plants, ranging up to 60,000 kw. General Electric Co., Schenectady, N. Y.

Safety Switches.—Catalog, 56 pp., entitled "Westinghouse Safety Switches," describes industrial, motor starting and meter service switches. Westinghouse Electric & Mfg. Company, East Pittsburgh.

Switchboards.—Bulletin No. 1006-2, 16 pp. Describes construction and pictures installations of Condit switchboards in various industries. Condit Electrical Mfg. Corporation, Boston, Mass.

Automatic Switching Equipment.—Bulletin GEA-295, 24 pp. Describes the application of automatic switching equipment to railway service, hydro-electric generators, mining, industrial, central station service, etc. General Electric Company, Schenectady, N. Y.

Rail Bond Testers. Bulletin 200, 8 pp. The Type BBT bond tester and Type B contact bar described are new devices just placed on the market. The particular application of the new tester lies where the current on the rail is very feeble, or absent altogether. The sensitivity of the new device is claimed to be five times as great as any heretofore made. It can be used with the current from a single No. 6 dry cell. Roller-Smith Company, 12 Park Place, New York.

Automatic Direct-Current Starter.—Bulletin 215, 4 pp. Describes Type C-1220 current limit automatic d-c. starter, for use in starting constant speed shunt or compound wound motors up to 30 h. p., 115 volts; and 50 h. p., 230 or 500 volts, for any applications where it is desired that the time of acceleration correspond with the load on the motor. **Crane, Hoist and Mill Controller.** Bulletin 330, 8 pp. Describes Type F-2250 controllers, for general crane and mill service. Allen-Bradley Company, Milwaukee, Wis.

NOTES OF THE INDUSTRY

Simplex Wire & Cable Company, Boston, has opened a branch office in the Union Trust Building, Cleveland, in order to better care for a steadily increasing volume of business. William H. Lamond will be manager of the new office.

Kohlenite Products Company, Inc., New York, manufacturer of carbon brushes, has opened a branch office located at 1555 Monadnock Block, Chicago. This office will be in charge of H. A. Hallead.

The Griscom-Russell Company has moved its general offices in New York to the new Murray Hill building, 285 Madison Avenue.

The Foxboro Company, Inc., Foxboro, Mass., maker of indicating, recording and controlling instruments, has moved its Pittsburgh office from the Park Building to what will now be known as the Foxboro Building, located at the corner of Sixth Avenue and Grant Street. The four upper floors will be utilized for offices and the maintenance of a substantial stock of new equipment.

130,000 Kilowatts to be Added to Detroit Power Supply.—Three turbine generators, totalling 130,000 kilowatts in capacity, are to be added to the facilities of the Detroit Edison Company. Two of these machines, 50,000 kw. each, will be placed in the Trenton Channel station, and the other, 30,000 kw., in the Marysville station. The turbines are being made by the General Electric Company and will be delivered within eight months.

Largest Lighting Contract to Westinghouse.—What is said to be the largest contract for street lighting equipment ever placed, consisting of 10,000 standard lighting units, reflectors and auxiliary equipment, was recently awarded to the Westinghouse Electric & Mfg. Company through the Ryckoff Construction Company of Chicago for a new street lighting system for the City of St. Louis. A plant will be erected in St. Louis for delivery of the hollowspun concrete poles at the rate of 1000 each month, as required by the contract.

General Radio Company Promotions.—At the annual meeting of the company on January 12, the position of Chairman of the Board of Directors was created to meet the growth of the company. Henry S. Shaw, Treasurer for the past eight years, was elected to this position. H. B. Richmond, formerly Secretary and Assistant Treasurer, was elected to the position of Treasurer. No other changes were made in the officers; Melville Eastham who has served as President for the past eleven years will continue in that office and E. H. Locke enters his sixth year as Vice-President, in charge of manufacturing. During the past year the company completed its new factory at Cambridge, Mass., which provides 50,000 square feet of ideal manufacturing space.

Master Electric Sales Conference.—On January 11 and 12 the branch office representatives and the distributing agents of The Master Electric Company met at the factory, Dayton, Ohio, for a sales conference. The primary object of the meeting was to acquaint the field organization with the greatly increased facilities offered by the new plant at Linden and Master Avenues and into which the company just recently moved. On the evening of January 11 the visiting representatives and a number of plant executives held a banquet at the Engineers Club.

General Electric Orders for 1925.—Orders received by the General Electric Company for the year ending December 31, 1925, amounted to $302,513,380, according to an announcement by Gerard Swope, president of the company. Compared with $283,107,697 for the year 1924, this is an increase of seven per cent. For the three months ending December 31, 1925, orders totalled $78,636,669, compared with $80,009,978 for the same quarter of 1924, a decrease of two per cent.

Sales Organization Changes in W. N. Matthews Corporation.—Louis M. Meckler has succeeded W. J. McIlvane as New York representative of the W. N. Matthews Corporation, St. Louis, manufacturers of Matthews electrical specialties. The Baltimore territory, which was formerly covered by Mr. McIlvaine, will be under the supervision of H. C. Biglin, southern district manager of the corporation. J. T. Pearson, district manager in Detroit, has resigned and this territory will be covered by H. L. Brueck, Chicago district manager. The Iowa territory which was formerly covered by Mr. Brueck will be taken care of by W. M. Watters. The northern section of Pennsylvania, which has been covered by the New York office, has been transferred to J. A. Jaques of the Pittsburgh office.

J. H. Bunnell & Company Changes Hands.—Control of J. H. Bunnell & Company, founded in 1879 and known as one of the world's leading manufacturers of high-grade telegraph apparatus; also as manufacturers of fire alarm apparatus and other electrical equipment, has been acquired by J. J. Raftery and J. G. Dougherty. Mr. Raftery was previously connected with the Western Electric Co., and later with Manhattan Electrical Supply Co., Inc., as Eastern General Manager. Mr. Dougherty was formerly with the Illinois Steel Corporation. The retiring President, J. J. Ghegan, who has been associated with Bunnell for forty years, will retain a financial interest in the business and will continue to give it the benefit of his long experience. Plans for expansion are being worked out.